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GEOLOGICAL MAGAZINE

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Current-Bedding in the Moine Series of North-Western Scotland

By GILBERT WILSON, JANET WATSON, and JOHN SUTTON

ABSTRACT

This note records a number of observations of orientation of current-bedding in the Moine Series of Inverness-shire, Wester Ross and Sutherland, in the North-Western Highlands of Scotland. The foreset beds have been found to have a dominant dip towards the north, thus suggesting that the currents responsible for the transport of the material forming these beds flowed from the south.

I. INTRODUCTION

THE presence of false-bedding in the Moine Series in parts of Sutherland and Ross-shire was recorded many years ago by the officers of the Geological Survey. The localities particularly noted were near Loch Merkland Lodge (*Geol. Surv. Ann. Rept.* for 1896, p. 16), in the vicinity of Loch Shin in Sutherland, in Rhidorroch Forest in Ross-shire (at which two localities, Dr. J. E. Richey informs us, false-bedding is indicated on the 6-in. field maps of the Geological Survey), and at numerous places in Easter Ross in the country covered by 1-in. sheet 93, especially around Carn Chuinneag (Peach and others, 1912).

The orientation of the Moinian current-bedding and its significance was, however, not appreciated till many years later, when in 1939 Richey and Kennedy reported the discovery of well-preserved sedimentary structures near Arisaig and Morar in Inverness-shire. It was deduced that the prevalent set of the currents which carried the sediment lay slightly east of north over a 30 mile stretch from Loch Nevis southwards to Loch Sunart (Phemister, 1948, p. 20). Richey and Kennedy's (1939) paper contains also the first use of sedimentary structures to determine the correct Moinian succession.

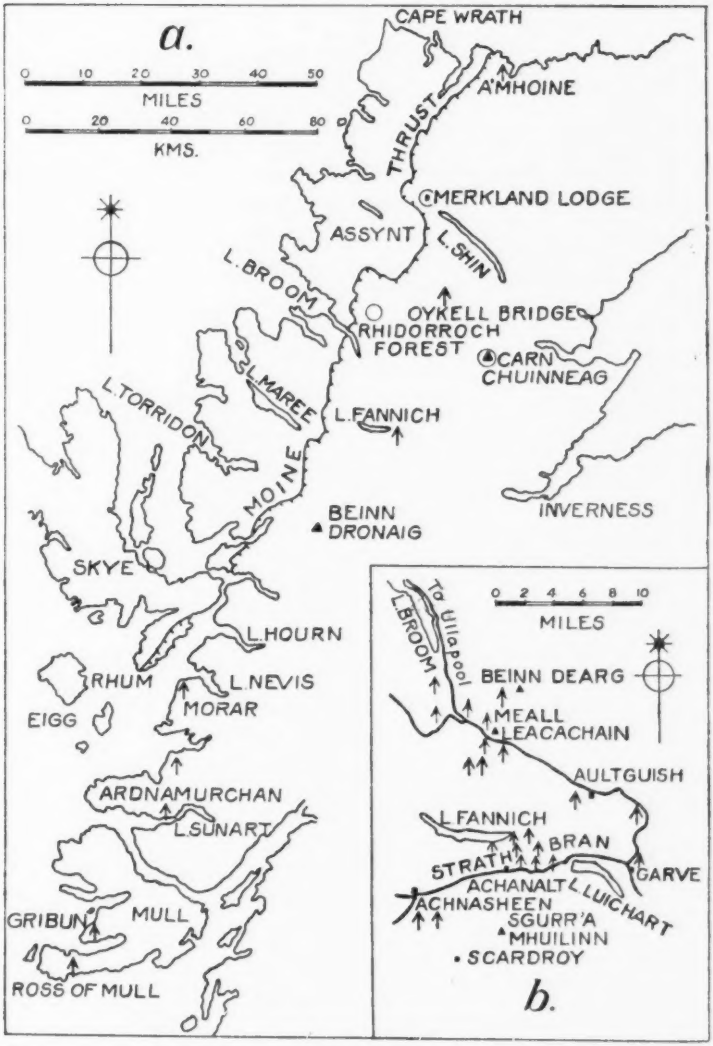
At the 1951 meeting of the British Association in Edinburgh Dr. Richey reviewed the conditions of deposition of the Moine and Torridonian rocks. He mentioned further examples of northerly-

directed current-bedding from Inverness-shire and referred to other observations which we had at various times communicated to him. Dr. Richey drew attention to the fact that, though the recorded occurrences of false-bedding in the Moines indicate transport by currents flowing from southerly directions, the published accounts of similar structures in the Torridonian showed that, in that formation, the current-bedding is inclined to the south-east or east, and therefore resulted from currents that flowed from the north-west or west (Peach and others, 1907, pp. 293, 332; Phemister, 1948, p. 42).

The observations presented now provide further support for the point made by Dr. Richey in 1951. The localities from which northerly-directed current-bedding has been recorded are shown in Text-fig. 1. Our experience has been that, although the majority of the foreset beds dip northwards, individual beds in which the current-bedding was originally inclined southwards can also be found intercalated within strata showing the more usual orientation. Such occurrences indicate changes in the directions of the currents and remind one that local factors may have controlled the attitude of the crossed lamination. Nevertheless any worker studying the Moine Series should take into account the fact that, at a number of widely dispersed localities, the false-bedding in the Moine Series is inclined in northerly rather than southerly directions, from which it must be inferred that the predominant direction of transport was from the south.

As it is rarely that the outcrops provide a three-dimensional view of the current-bedding, it is only possible to say that the cross-lamination (when the attitude of the rocks has been restored to the horizontal) dips predominantly in a northerly rather than a southerly direction. Thus " northerly " is used throughout this paper to indicate that a generally northerly component is present, and it does not imply that the currents flowed precisely towards the true north.

Individual layers in the Moine Series that show current-bedding rarely exceed 1 foot in thickness, and are much more commonly less than 6 inches across. The Moinian false-bedding thus presents a marked contrast to that found in the Torridonian west of the Moine Thrust, for example in Wester Ross. Near Loch Maree and on the coast between Gairloch and Loch Torridon the units of sedimentation in the Torridonian are often considerably greater than in the Moines, and individual beds showing crossed lamination may exceed 2 feet in thickness. This difference between Moinian and Torridonian rocks cannot be ascribed to the deformation of the Moines, for the angle between the normal stratification and the inclined crossed lamination in the Moines commonly approaches the angle of rest of uncemented sand; this would be unlikely had the rocks in question been attenuated and thinned. The small scale of the current-bedding, which is



TEXT-FIG. 1.—(*a*) Sketch-map of North-West Scotland. Localities where northerly inclined current-bedding has been observed are shown by arrows. Other localities where current-bedding has been recorded, but its orientation is not known are shown by circles.
(*b*) Sketch map of the area around Loch Fannich.

undoubtedly an original feature of these rocks, suggests that the Moines accumulated less rapidly than did the Torridonian.

Locally the individual laminae in current-bedded Moines are more

than usually curved, and appear to have reached this state before the overlying beds, which are undisturbed, were deposited. Slumping, as reported by Richey and Kennedy (1939), can be observed in some of the granulites; these may contain detached fragments that can be distinguished by their contrasting lithology from the folded matrix around them. Such strongly contorted beds are commonly overlain by undisturbed strata which can in some places be seen to truncate the underlying structures. Graded bedding can locally be seen in the slumped beds, and in the beds immediately above them. It also occurs in certain grit bands which are found in the lowest stratigraphical group so far recognized in Central Ross.

The areas shown in Text-fig. 1, in which the orientation of current-bedding in the local Moine Series has been noted during the course of mapping, are from south to north, as follows:—

Ross of Mull and Gribun, Isle of Mull . .	G.W.
Western Inverness-shire; Loch Sunart to Morar and Loch Nevis, a distance of about 30 miles (19 km.).	Richey & Kennedy, 1939. Phemister, 1948.
Fannich Mountains, Wester and Central Ross-shire.	J. S. and J. W.
Oykell Bridge on the Ross–Sutherland boundary.	G. W.
A'Mhoine, North Sutherland . . .	G. W.

The writers wish to record their gratitude to Dr. J. E. Richey, without whose encouragement this paper would not have been written, and to Professor H. H. Read for a critical reading of the text.

II. The Ross of Mull and Gribun, Isle of Mull

Metamorphosed sediments that have been correlated with the Moine Series of the Scottish mainland occur in the Ross of Mull; in a few scattered islets off the west coast of the Island; at Gribun, which is also on the west coast; and in the "Mull Inliers" which crop out within the Tertiary volcanic complex. These exposures form the most south-westerly occurrences of the Moine Series in Scotland. Current-bedding has been observed in the rocks of the Ross of Mull and of Gribun; it was not found in those of the Mull Inliers on Sgurr Dearg nor has it been reported in any of the others.

The Moinian sediments of the Ross of Mull have a general north-north-easterly strike, and dip steeply. Bailey (Lee and Bailey, 1925) recognized that there was a symmetrical repetition of the main rock-groups when they were traversed across their strike, and suggested that this might be due to a large isoclinal fold. Recent mapping has shown that this fold does exist and is a syncline which plunges at

about 32 degrees to the south-south-west. The large-scale structure can be clearly demonstrated by inward-facing current-bedding in two outcrop areas of coarse psammitic granulite. These two areas are separated by some 5 miles of strongly folded siliceous, semi-pelitic, and pelitic Moine Schists. The coarse psammitic rocks form the outermost (or lowest) beds of the major structure, and they can be followed northwards in scattered islets to the coastal area of Gribun. This group has been tentatively correlated with the " Upper Psammitic Group " of Morar (Richey and Kennedy, 1939), to which it is very similar.

Current-bedding and minor slump structures are common within the coarse psammitic beds, and the truncated tops of the cross-laminations leave no doubt as to the order of the stratigraphical sequence. The asymptotic bottoms of the laminae with one or two exceptions thin towards the north. The currents responsible for the formation of the false-bedded structure must therefore have flowed dominantly from the south.

At Gribun similar rocks crop out below Triassic beds and Tertiary lavas. They are well exposed on the shore and on a gently rising bench feature that can be followed southwards; the total length of the outcrop area is about 2 miles. The Moinian rocks dip gently (20–30 degrees) towards the south-west, and as in the Ross, the foreset laminae of the current-bedding dip northwards—with few exceptions—indicating that their deposition was also due to currents flowing from the south.

The Gribun and Ross of Mull areas lie between 20 and 28 miles south-south-west of the mouth of Loch Sunart, beyond which northward-facing current-bedding has been recognized for some 30 miles further north (Phemister, 1948, p. 20). The observations made in southwest Mull would seem to prolong this last figure up to a total of nearly 60 miles ; but the Moinian rocks between Gribun and the coast of Ardnamurchan are buried below Teritary basalt flows, so that definite continuity of the current-bedding structure cannot be established.

III. Fannich Mountains, Wester and Central Ross-shire

Current-bedding has been observed by two of us (J. S. and J. W.) at fifty-five localities in Ross-shire during the last four years. These localities are distributed irregularly through a district approximately 170 square miles in extent. This area extends from Scardroy in the south to the neighbourhood of Inverbroom and Beinn Dearg, some 18 miles further north, and from the west of the Fannich Mountains, 2½ miles east of the line of the Moine Thrust, to the vicinity of Loch Luichart and Aultguish approximately 14 miles distant from the outcrop of the thrust-plane.

The frequency with which false-bedded rocks have been encountered in this ground varies greatly, such rocks being more abundant in the north and centre of the area than in the south. Current-bedding is particularly abundant near Achanalt, in the country near the east end of Loch Fannich and in a belt further north which crosses the Ullapool–Garve road about 3 miles south-east of Braemore.

Good and accessible localities for the study of current-bedded Moines include the wave-cut platform at the east end of Loch Fannich, the bed of the river which formerly drained Loch Fannich (before the hydro-electric scheme) at points ¼ mile south of Aultdearg, scattered outcrops on the knoll overlooking the main road and railway east of Achanalt to the north of the railway bridge over the River Bran, and the glaciated surfaces on the lowest slopes of Meall Leacachain immediately by the side of the Ullapool–Garve road (inset, Text-fig. 1).

The irregular geographical distribution of current-bedded Moines in this area seems to be the result of three factors: the false-bedding, like the slumping and graded-bedding, is restricted to certain members of the succession; permeation of the rocks by felspathic material has been more pronounced in the south near Scardroy, in the west near Achnasheen and in the western part of the Fannich range than elsewhere; and the style of folding is not the same throughout the area, deformation apparently being more marked in the south. The last two factors have diminished the chances of sedimentary structures remaining recognizable in the southern and western parts of the district.

The style of the folding has been dealt with elsewhere (Sutton and Watson, 1952 and 1953) and it is sufficient to say that whereas north of the Fannich watershed the major folds are not isoclinal, to the south of the watershed, isoclinal folding becomes the rule; further south still, south of Strath Bran, we have shown that on Sgùrr a Mhuilinn the folding was accompanied by a slide near which the rocks were mylonitized. It seems possible that regional deformation destroyed any original sedimentary structures over much of the ground south of Strath Bran: current-bedding can be found in the ground north of Strath Bran in granulites which, when followed along the strike to the south of the strath, show little or no current-bedding. Up to the present, in fact, current-bedding has been found only at two places south of Strath Bran. A careful search further south around Scardroy revealed no trace of current-bedding, and Mr. J. G. Ramsay, working further south still near Loch Monar, tells us that he found no current-bedded Moines during a season's fieldwork in that area.

The northern and eastern parts of the district, on the other hand, are quite different. Throughout a belt of country running from the head of Loch Broom eastward to Aultguish and south-eastward to

Achanalt and Loch Luichart current-bedding is preserved at many points. It appears to be consistently more common in certain rock bands than in others, and in some groups none at all has been seen; it is possible that these contrasts genuinely reflect original features of the Moine sedimentation.

We have recently proposed a major revision of the Moine succession in the Fannich Mountains and Central Ross-shire. Current-bedded granulites are most frequently found in the lowest group of our succession, the Achanalt Semi-pelitic Group, which also contains all the examples of slumping and of graded grit bands which have so far been noted.

The overlying Droma Pelitic Group is succeeded by the thickest lithological group in the succession, the Inverbroom Semi-pelitic Group, made up of 6,000–8,000 feet of siliceous and semi-pelitic granulites (these were previously classified as the Upper Siliceous Group, but as they are demonstrably overlain by a further 3,000 feet of Moines, we have abandoned this name; see Sutton and Watson, 1953). Current-bedding appears to be commoner in the lower parts of this group than in the upper, although near Braemore current-bedded granulites are seen which lie near the top of the Group. Only two examples of current-bedding have been recognized from any granulites overlying the Inverbroom Group; this is partly explained by the fact that some of the outcrops of these groups lie within the granitized Fannich permeation complex, but a careful search of well exposed beds outside the felspathized area suggests that current-bedding is rare at these stratigraphical levels.

The highest current-bedded horizon lies stratigraphically some 12,000 feet above the base of the Achanalt Group, in which occur the lowest examples of current-bedding so far recognized. Although the observations are never numerous and become progressively rarer in the upper parts of the succession, all the records made within this thickness of Moine sediments, the base of which is not seen, indicate that the currents responsible for the deposition of the sediments flowed predominantly from the south.

Up to the present we have made only scattered observations in the eastern district covered by the Geological Survey Sheet 93. It is clear, however, from the work of the Geological Survey in the east and from our own investigations in the west, that sedimentary features are preserved in the Moines at fairly frequent intervals through a belt stretching almost the whole way across the Moine outcrop from near Loch Broom in the west to the ground east of Carn Chuinneag. In the west the southern limit of this belt appears to lie near Strath Bran: the position of the southern limit further east is not clear, for current-bedding was recorded by Hinxman from unspecified localities

in the Inverness Memoir (1914, p. 24). The northern limit of the ground where current-bedding may be found is not known.

The interest of this belt lies in the fact that it may provide some information about the deposition of the Moines over a belt stretching some 25 miles from west to east, whereas most of the information available up to now has come from localities not far distant from the Moine Thrust and thus consistently in the western outcrops of the Moines.

IV. The Oykell Bridge Area

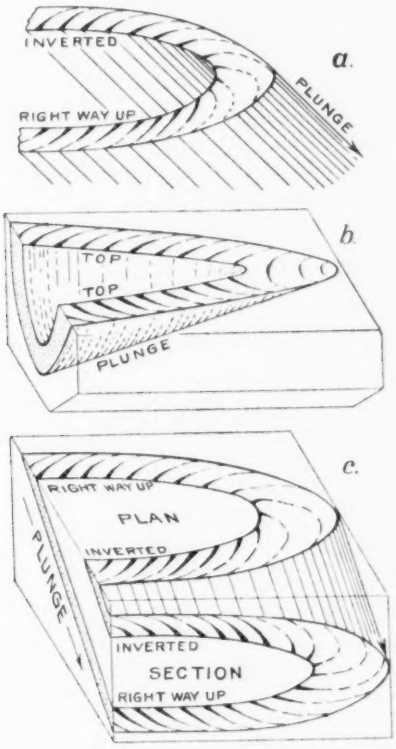
Current-bedding was observed in about half a dozen exposures in the neighbourhood of Oykell Bridge which lies on the boundary between Ross-shire on the south and Sutherland on the north. The general geological setting of the area is included in Read and Phemister (1926), and the local structure has been discussed in Wilson (1953). The rocks of the area are dominantly siliceous Moine granulites which strike north-west and dip from 45 degrees to over 90 degrees to the south-west. The truncated tops of the cross-laminae also face towards the south-west. Exposures showing current-bedding were found in the banks of the Oykell River between the two bridges and in the gorge below Oykell Falls; but the best examples are to be seen on the hill of Bhein Beag which overlooks the Oykell valley about 1½ miles north-west of the bridges. The current-bedding laminae here are etched out on the weathered rock-surfaces and clearly show that not only do the tops of the beds face south-west, but that the asymptotic bottoms thin towards the north or north-west, in which direction the original currents must have been flowing.

V. A'Mhoine, North Sutherland

The desolate peat-covered plateau of A'Mhoine (*gaelic*: the peat-moss) in the extreme north of Sutherland is the area from which the Moine Series derived its name. The rocks encountered there are "typical siliceous and semi-pelitic Moine granulites, with less common layers of interbedded garnet-mica-schist, Durcha-type hornblendic granulites and garnetiferous amphibolites" (Wilson, 1953, p. 131; 1 in. to 1 mile Geol. Surv. map, Sheet No. 114). Current-bedding has, so far, been found at one locality only: in a low cliff on the east side of Loch Vasgo. This little lake lies in the fork of the road which leads from Midtown and Talmine to Strath Melness in the west and to Port Vasgo in the north; the road-fork is approximately 1 mile north-north-west of Talmine Post Office. As in the other occurrences described in this paper, the foreset beds dip northwards, indicating that, even in this most northerly of the observed exposures, the uniform direction of the original currents was still being maintained. It should, however, be recalled that though current-bedding is known

to occur at Loch Shin and Merkland Lodge there is a stretch of 40 miles between North Sutherland and Oykell Bridge in which its orientation has not been recorded.

The beds in this area are strongly folded into isoclinal recumbent folds which plunge easterly. These structures are well exposed in cross-



TEXT-FIG. 2.—(*a*) Simplified diagram showing the style of folding of the current-bedding by Loch Vasgo, A'Mhoine.

(*b*) Block-diagram showing the folding of current-bedding on a fold-axis which plunges approximately parallel to the direction of dip of the laminae.

(*c*) Block-diagram showing plan and sectional views of current-bedding folded roughly at right-angles to the direction of dip of the laminae. Note the apparent reversal of the direction in which the crossed laminae thin in the inverted limb.

section on *ac*-joint surfaces, so that, at Loch Vasgo, one can clearly follow the inversion of the current-bedding around the flexure (Text-fig. 2*a*). It is at once seen that the asymptotic bottoms of the inverted beds point and thin *in the opposite direction* to those in the strata which

are right way up. In the Ross of Mull, however, though the rocks have been strongly folded also, the foreset beds face in the same general direction on either side of the fold. This is because the fold-axis is approximately parallel to the original direction of dip of the foreset laminae, and the current-bedding has been flexed across its strike (Text-fig. 2*b*).

This difference in orientation of folded current-bedding may, in future, be of value in the interpretation of folds in the Moine Series; provided that, throughout any particular area in question, reasonable uniformity of the cross-bedding orientation can first be established. Thus, should exposures of inverted and uninverted strata both contain current-bedding of which the asymptotic bottoms point and thin in the same direction (Text-fig. 2*b*), the fold axis *b* will be roughly parallel to that direction. If, however, the inverted and uninverted current-bedding laminae face in opposite directions (Text-fig. 2*c*), the fold-axis *b* will lie more or less at right angles to the original dip-direction of the laminae, or roughly parallel to their strike.

When Richey and Kennedy originally presented their paper on the succession and structure of the Moine Schists of the Morar district to the Geological Society in 1938, Sir Edward Bailey made the following comment: "The consistent direction of the current-bedding, easily demonstrable through vast thicknesses in the upturned beds, was perhaps the most surprising single phenomenon." The same direction of current-bedding has now been recognized at irregularly spaced localities over a tract of country extending for a distance of 170 miles (270 kms.) from Mull to the north of Sutherland. The phenomenon thus seems to be of regional interest, and although its full significance cannot be assessed until the intervening ground has been examined, it may play an important part in elucidating the problems of the Moines.

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The Miocene/Oligocene Boundary and the Use of the Term Aquitanian

By F. E. Eames [1]

Abstract

It is considered that some fossils, e.g. *Orbulina* and *Miogypsina*, are good indicators that beds containing them are of post-Oligocene age, and that the ages of some beds in certain parts of the world require reconsideration; mention is made of successions in Morocco, Venezuela, and Peru. It is recommended that the use of the term "Aquitanian" be restricted to beds of basal Miocene age.

FOR many years it has been apparent that the term "Aquitanian" has been used in different senses and for rocks of different ages. Some writers use it for beds of basal Miocene age, and some for beds of Upper Oligocene age; to the latter school belong many Continental and American workers. Since the term has been applied to beds with either Miocene or Oligocene faunas, great confusion has arisen in literature. Furthermore, certain useful Miocene index-fossils have had their ranges unjustifiably extended down into the Oligocene, and much useful information is in danger of being lost.

Haug (1908–1911) showed that, in its type area, the beds constituting the Aquitanian form the basal component of the first Mediterranean transgression; the fauna is obviously related to the overlying Miocene beds (a number of significant species being in common), and is not to be grouped with the Oligocene. Durham (1944) suggests that an earlier use of the term applies to beds near Ajoie in Switzerland, which are now believed to be of Chattian age. Dehm (1949) and Rutsch (1951) cast doubt upon this interpretation. It seems to the writer that, just as the type section for the Bartonian must be in the Hampshire Basin and not in the Paris Basin (the sense in which some authors are prone to use it), so the type section for the Aquitanian must be in Aquitaine and not in Switzerland; it seems an ideal case for applying the palaeontological principle of "tautonymy", and regarding the earlier (Oligocene?) use as a "nomen nudum", especially as there appear to be doubts of interpretation.

Some authors, e.g. Gignoux (1950), place the Aquitanian in the Upper Oligocene on account of the nature of the vertebrate fauna in equivalent terrestrial beds. Quite apart from the facts that the evolution of the vertebrate faunas is not pertinent and that the stages of the Tertiary are primarily based on marine faunas, there can be no question that the type Aquitanian of Aquitaine must be regarded as basal Miocene.

[1] Published by permission of the Chairman and Directors of the Anglo-Iranian Oil Co., Ltd.

A few cases of evident misinterpretation of age will now be considered.

Morocco

Brönnimann has described species of *Miogypsina* from beds in Morocco called Chattian and Aquitanian (regarded as Upper Oligocene). A study of his paper reveals that, while his palaeontological descriptive work is excellent, he has made no analysis of the evidence, and accepts the age-indications given by Senn (1935) who wrote the earlier stratigraphical paper. Senn, without assessing the evidence, gives the following succession:—

Age Suggested.	*Senn.*
Burdigalian	Burdigalian (*Lepidocyclina tournoueri*, *Miogypsina irregularis*, *M.* sp., *Amphistegina*).
Aquitanian	Aquitanian (*Lepidocyclina tournoueri*, *Miogypsinoides* [*Miogypsina*] *complanata*, *Miogypsina irregularis*).
Oligocene	Chattian (*Nummulites*—very small and rare, *Operculina*, *Heterostegina*, *Amphistegina*, *Lepidocyclina tournoueri*, *L. tournoueri* var. *simplex*, *L. marginata* var. *praemarginata*, *L. dilatata*, *L. dilatata* var. *eodilatata*, *Miogypsinoides* [*Miogypsina*] *complanata*, *Miogypsina irregularis*).
	Rupelian (*Nummulites*—small striate forms, *Operculina*, *Heterostegina*, *Amphistegina*, *Lepidocyclina tournoueri*, *L. tournoueri* var. *simplex*, *L. tournoueri* var. *praetournoueri*, *L. marginata*, *L. marginata* var. *praemarginata*, *L. partita*, *L. dilatata*, *L. dilatata* var. *eodilatata*, *L. raulini*).
	Lattorfian (*Nummulites*—small striate forms, *N.* cf. *fichteli*, *Operculina*, *Heterostegina*, *Amphistegina*, *Lepidocyclina tournoueri*, *L. tournoueri* var. *simplex*, *L. marginata*, *L. marginata* var. *praemarginata*, *L. partita*, *L. dilatata*, *L. dilatata* var. *eodilatata*).
Bartonian (= Wemmelian)	Wemmelian (c) (*Nummulites incrassatus*, *N. fabianii*, *Hantkenina*). (b) (*Nummulites*—small, striate, *N.* cf. *fabianii*, *Operculina*, *Heterostegina*, *Discocyclina pratti*, *D. nummulitica*, *D. strophiolata*, *Asterocyclina stellaris*, *Aktinocyclina* cf. *radians*, *Lepidocyclina tournoueri* var. *praetournoueri*, *Hantkenina alabamensis*, *Bulimina jacksonensis*, *Baculogypsinoides tetraedra*.)

The uppermost Eocene age of the Wemmelian beds is perfectly satisfactory. The *Discocyclinas*, *Nummulites fabianii*, *Hantkenina*, *Asterocyclina*, and *Aktinocyclina* are a typical uppermost Eocene suite, with which small simple *Lepidocyclina* (*Nephrolepidina*) [1] are

[1] *L. tournoueri* belongs to the subgenus *Nephrolepidina*.

sometimes associated. There is a marked palaeontological break between the Wemmelian and the so-called " Lattorfian ", *Discocyclina*, *Asterocyclina*, and *Hantkenina* becoming extinct, and *Nummulites*, cf. *fichteli* and a new suite of *Lepidocyclinas* suddenly appearing. To the writer this strongly suggests that the Lattorfian (approximately) is missing, and that the so-called Moroccan " Lattorfian " is really Rupelian. The so-called " Rupelian ", with small striate *Nummulites* but no reticulate forms is apparently Chattian.

It seems that the so-called " Chattian " and Aquitanian are both of Aquitanian (Lower Miocene) age, since both contain *Miogypsina*. It is my opinion that the " very small and rare " " *Nummulites* " from the " Chattian " are almost certainly not *Nummulites*, but probably *Operculinella*.[1] The presence of *Miogypsina* in the beds referred to the Burdigalian is quite consistent with such an age.

Venezuela

Senn (1935) has recorded the following succession from north-west Venezuela:—

Age Suggested.	*Senn.*
U. Miocene	U. Miocene La Vela Formation (Mollusca).
M. Miocene	M. Miocene Damsite Formation (many mollusca, *Miogypsina*, *Amphistegina*, *Heterostegina*, *Sorites*, *Bolivina*, *Spiroloculina*, *Clypeaster*).
Burdigalian	L. Miocene Socorro Formation (*Turritella abrupta*). U.U. Oligocene Cerro-Pelado Formation (*Lepidocyclina*, *Miogypsina*).
Aquitanian	L.U. Oligocene Aguaclara Formation (Shales with local basal conglomerate) (*Lepidocyclina*, *Miogypsina staufferi*, *Cristellaria calcar*, *C. clericii*, *Spiroclypeus*, *? Lepidocyclina canellei*, *Heterostegina*, *Amphistegina*). M. Oligocene San Luis Formation. U. San Luis Formation (limestone) (*Lepidocyclina sanluisensis*, *L.* cf. *antiguensis*, *L. canellei*, *L. forresti*, *Miogypsina hawkinsi*, *Nummulites*—rare and small, *Heterostegina* cf. *antillae*, *Spirocylpeus*). M. San Luis Formation (shale) *Lepidocyclina*, *Nummulites*—rare and small, *Miogypsina*). L. San Luis Formation (shale and limestone) (*Lepidocyclina*, *L.* cf. *marginata*, *L. undosa*, *L. favosa*, *Miogypsina*, *Nummulites*—rare and small, *Spiroclypeus*, *Heterostegina*).
Rupelian	L. Oligocene Churuguara Shales (*Nummulites*, *Heterostegina* cf. *antillea*, *Lepidocyclina canellei*, *L. falconensis*, *L. undosa*, *L. gigas*, *L. senni*, *Miogypsinoides* [*Miogypsina*] cf. *complanata*, *Miogypsina hawkinsi ?*).

[1] Using the term *Operculinella* for miniature *Nummulites*-like forms, of small size, with a very small megalospheric nucleoconch, with little difference in size between the two generations, with or without a tendency to flare in old age. It seems very necessary to retain the name *Nummulites* only for those forms, such as *N. atacicus*, *N. obtusus*, *N. laevigatus*, *N. millecaput*, *N. intermedius*, and *N. vascus*, which characterize the Palaeogene.

Age Suggested.	*Senn.*
U. Eocene	U. Eocene–L. Oligocene Jarillal Shales (*Raetomya schweinfurthi* var. *falconensis*, *Ectinochilus gaudichaudi* var. *alauda*, *Tellina*, *Mactra*, *Lutraria*, *Xanthopsis rathbuni*, *Falconoplax kugleri*, *Heterostegina*, *Nummulites*, *Raninoides rathbunae*, *Eoinachoides senni*).
	U. Eocene Santa Rita Conglomerates (*Discocyclina flintensis*, *Asterocyclina georgiana*, *A. asterisca*, *Lepidocyclina adkinsi*, *L. trinitatis*, *Nummulites* cf. *parvulus*, *Operculina* cf. *cookei*, *Spiroclypeus*, *Bulimina jacksonensis*, *Raetomya schweinfurthi* var. *falconensis*, *Ectinochilus gaudichaudi* var. *alauda*, *Nuculana*, *Arca*, *Glycymeris*, *Pecten*, "*Cardium*," *Clementia*, *Dosinia*, *Chione*, *Corbula*, *Architectonica*, "*Natica*," *Turritella*, *Clava*, *Lyria*, *Oliva*, *Turris*, *Conus*, nautiloids).

The Upper Eocene age of the Santa Rita conglomerates, with *Discocyclina*, *Asterocyclina*, *Spiroclypeus*, and *Raetomya*, is well-established. The Jarillal Shales, with *Raetomya* and the same *Ectinochilus* also appear to be of Upper Eocene age, there being no evidence of any Oligocene element in the fauna.

In the Churuguara Shales a different suite of *Lepidocyclinas* suddenly appears, and the queried occurrence of *Miogypsina hawkinsi* is to be disregarded. The presence of *Miogypsinoides* indicates an age not older than Middle Oligocene. It appears that there is a palaeontological and stratigraphical break above the Jarillal Shales, that the Lattorfian (L. Oligocene) is missing, and that the Churuguara Shales are of Rupelian age.

In the San Luis Formation it is again my opinion that the "rare and small" "*Nummulites*" are almost certainly not Nummulites, but probably *Operculinella*. The presence of *Miogypsina* in all beds from the Lower San Luis Formation up to the Damsite Formation (except for the Socorro Formation, which contains gastropoda only) indicates that these beds range in age from Aquitanian (basal Miocene) to Middle Miocene; since the Aguaclara Formation contains *Spiroclypeus* (not ranging above Aquitanian), both it and the San Luis Formation are of Aquitanian (basal Miocene) age.

There are other cases in which similar confusion with regard to the Miocene–Oligocene boundary has arisen. A careful analysis of all the evidence has convinced the writer that there are a number of well known forms with worldwide distribution that are particularly useful for age-determination. *Miogypsina* (basal Miocene to Middle Miocene) is but one instance. *Orbulina* (Neogene) is another, and Le Roy's recent paper (1948) on the worldwide range of *Orbulina universa*, which is shown to occur as low as "Oligocene" only in the Central American region, is an important and significant contribution to the study of Tertiary faunas.

Peru

One further example is that of Stainforth & Rüegg (1953) who, in discussing beds in Peru, write:—

> " However, a very important microfauna was discovered in one sample near the base " (of the Camana formation). " The assemblage consists of the two species *Miogypsina* (*Miogypsina*) *gunteri* and *Miogypsina* (*Miolepidocyclina*) *ecuadorensis*, together with less significant smaller Foraminifera. Drooger has lately demonstrated the evolutionary pattern of *Miogypsina* in the Caribbean region and it is clear from his records that the basal Camana fauna is late middle or earliest Upper Oligocene."

To the writer it seems quite clear that this is a Lower Miocene transgression, not a mid-Oligocene transgression as suggested by the writers.

In conclusion it is recommended that the term " Aquitanian " be used in future *only* for beds and faunas known to be of basal Miocene age, the term Chattian being available for the Upper Oligocene. Furthermore, particular care should be taken in the analysis and assessment of previously published work in view of the incorrect use to which the term " Aquitanian " has been put and of the consequent exaggerated ranges of some useful index-fossils, both genera and species.

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From Dolerite to Diorite: Older Granite Activity near Ellon, Aberdeenshire

By O. C. Farquhar

Abstract

Hornblende-schists, probably intruded as dolerite sills, have been permeated by trondhjemitic material. Conversion to rocks of dioritic aspect is the end-stage of this process, but the intermediate stages are more common. The conversion has been effected with little displacement so that all varieties can be observed in their correct sequence.

I. Introduction

In a recent paper on migmatitic and magmatic activity in the Ellon district of Aberdeenshire, Read and Farquhar (1952B) have shown that the various types of Highland Schist country-rock react with incoming material to give migmatite products of different kinds. The present paper is concerned with the detailed examination of one such product, that arising through migmatization of older basic rocks. These Read and Farquhar called migmatites of Kinharrachie Type. They were mentioned as diorites by Wilson (1886) and briefly described by Read (1923A and 1952A).

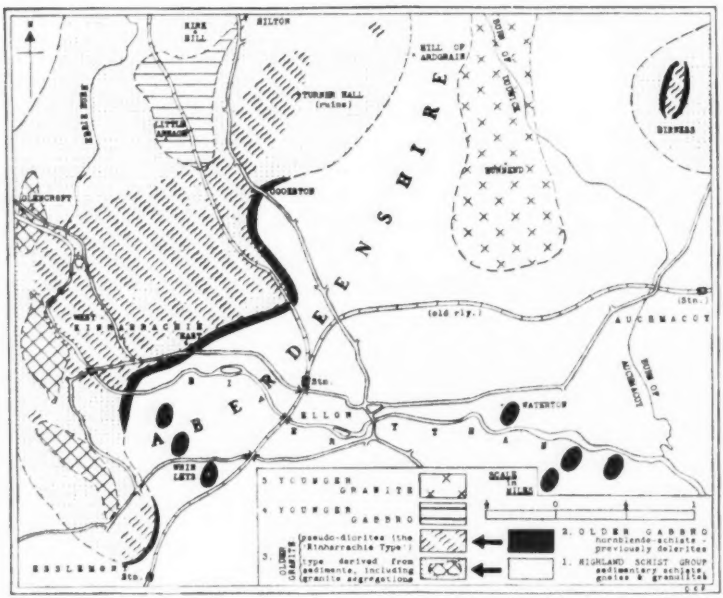
The basic country-rock parent was intruded as small sills of dolerite before the impress of the regional metamorphism. Hornblende-schists, as the metamorphosed dolerites now appear, may be examined in various localities in the Ythan Valley above and below Ellon. At such points as Esslemont, East Kinharrachie, Turner Hall, Birness and Waterton (Text-fig. 1), they show little sign of veining and may be considered as remote from the migmatite centre. Some of these hornblende-schists, including those at the Birness exposure, are more veined than others, but none of them show, except in pegmatitic pockets, the pseudo-dioritic development which characterizes the rocks of West Kinharrachie and the railway cuttings west of Cookston. The largest expanse of migmatitic derivatives is found between the railway and the river close to Kinharrachie. It appears that all the hornblende masses are parts of discontinuous but otherwise concordant sheets in the country-rocks. They lie mainly along the S.S.W.–N.N.E. strike which marks the western limb of the Buchan anticline.

In general, it is found that the degree of migmatization of the older basic rocks lags behind that of the associated sedimentary rocks: the basic rocks are in fact "basic resisters" (Read, 1951, p. 15).

II. The Transition from Meta-dolerite to Pseudo-diorite

To illustrate the transition from meta-dolerite to pseudo-diorite it is proposed to examine, stage by stage, the petrography of the intermediate rocks. The examples chosen are typical of the series of exposures which serves to explain the origin of the Kinharrachie Type.

On transformation to pseudo-diorite the meta-dolerite shows an increase in veining, average grain-size and degree of recrystallization with a corresponding decrease in schistosity, ferro-magnesian content, and sharpness of vein margin.



Text-fig. 1.—The Ythan Valley near Ellon, Aberdeenshire.

The unmodified hornblende-schist of stage 0 comes from the Waterton exposure. Stages 1–3 show hornblende-schists veined by acid strings and may be examined in the Birness roadstone quarry or in the railway cuttings west of Cookston. The best place to study the hornblendic contaminated rocks with hornblende-schist inclusions (stages 4–6) is around West Kinharrachie in the wooded land between the River Ythan and the road past Glencroft. Normal hornblende-schists crop out on the south bank of the river, around Esslemont, Whin Leys, etc., and a complete passage from these rocks to dioritic

types north-westwards denotes increasing migmatization in that direction.

Stage 0. *Unveined Hornblende-schists : White Spots in some Varieties*

This stage comprises the original greenstones, dark hornblende-schists in which small quartz, plagioclase, and hornblende grains are interlayered with larger green hornblendes. Occasional white clots are found in certain bands near Waterton. These may represent the infillings of vesicles in the original dolerite. The usual variety however, is a normal hornblende-schist, which has been analysed (Table I). Text-fig. 2A represents a thin section of such a rock.

Stage 1. *Slender Acid Strings, Sporadically Distributed*

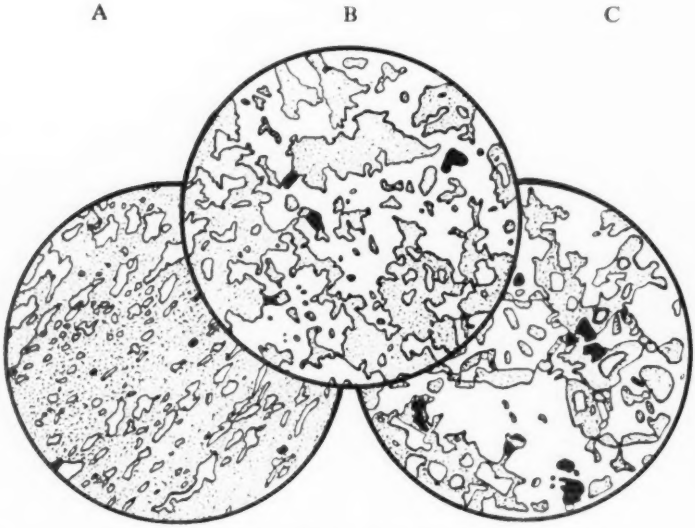
Rocks occurring in the wood surrounding Turner Hall show the first signs of infiltration. The white minerals begin to exhibit a patchy distribution and there has been some reconstitution of the schist. Recrystallization to produce hornfelses would ordinarily result in induration and a more compact interlocking of the constituent mineral particles upon loss of schistosity. But the entry of new material has counteracted these effects in the case of the rocks round Turner Hall and similar examples near Cookston and Esslemont. In the rocks of the Birness quarry it has been found that the veins consist chiefly of a plagioclase feldspar, oligoclase-andesine, in allotriomorphic grains. There is only a little quartz in the veins of the earlier phases of mixture, whereas a greater proportion appears in those rock-types which more nearly approach pseudo-diorite.

Stage 2. *Thoroughly Permeated : Occasional Clean-cut Veins*

Rocks of this stage, exemplified by material from the Birness quarry, have been more thoroughly permeated by the acid veins, and have assumed a speckled appearance. A large enough specimen shows a banding which does not depend altogether on the original schistosity but rather on a layering of the new minerals. The small-scale mixture is of too intimate a character to be described as lit-par-lit. The veins have, in fact, soaked into the whole mass so that individual threads have enveloped the crystals, especially hornblende, which lie along the walls of the vein-passages. Yet examples of hornblende-schist which are still in stage 1 also occur in the Birness quarry. Even stage 3 is represented here and it is evident that the invading veinstuff was distributed unequally in different parts of adjacent masses. Only tension joints can have controlled the allocation in this way: these nearly vertical fracture-planes are themselves filled with veinstuff.

Stage 3. Permeated and with Aplitic Patches: Large Hornblendes

The general base of the rock at this stage is similar to that found in stage 2, but it is evident that the physical conditions under which this more copious injection took place did not allow all of the incoming material to mix with the country-rock. Some of the incoming material has therefore remained in sub-parallel fissures, rarely along the residual schistosity, in which slow crystallization has prevailed. Where these fissures intersect or swell out enlarged cavities are seen to be filled with pegmatitic concentrations of leucocratic minerals. These vein-



TEXT-FIG. 2.—A. Hornblende-schist. Waterton.
B. Permeated hornblende-schist. Birness.
C. Pseudo-diorite. Kinharrachie. (Quartz and feldspar white; hornblende and biotite stippled; iron ores black. All × 18.)

pockets are also notable for a fine development of stumpy hornblende crystals up to 1½ in. in length. The regrown hornblendes are larger when in the aggregate they occupy a greater volume than the white minerals. When the black and white minerals occur in more equal quantities the hornblendes generally line the edges of the pegmatites. Adjacent to the vein margin the hornblende of the country-rock has also been recrystallized with a great increase in grain size. In the veins the andesine occurs in mutually-interfering aplitic grains with scarce anhedral quartz.

The occurrence of hornblende in pegmatite traversing hornblendic

rock has been noted by many observers (cf. Read, 1927, p. 343), and in a recent issue of this magazine Deer figured large porphyroblastic hornblendes in injected hornblende-schists of the Glen Tilt Complex (1953, p. 29). There seems no doubt that the hornblende-quartz-feldspar-pegmatites of the Ellon district result from reaction-processes linked with dissolution of pre-existing components in limited bands of the country-rock. The hornblende of the pseudo-dioritic matrix also comes from recrystallization of the original hornblendes rather than from the supply of new magmatic material. Many of the hornblendes in the early stages have concave borders and are evidently corroded. A thin section of the rock at this stage is represented in Text-fig. 2B.

Stage 4. *Certain Bands Recrystallized*

Stage 4 is marked by the production of a distinct new type of migmatitic rock. The difference between this and the last stage is by no means arbitrary but is based on a contrasting texture. There has plainly been more thorough mixing in addition to veining. The original schistosity is lost. The grain size is clearly larger and the rock has a new fluxional or gneissic appearance. The same pressure-temperature conditions under which mixture took place were almost certainly maintained during initial slow cooling in the crystallization phase.

More important than grain-size, however, is the new ratio of the light and the dark minerals which averages about 2 : 1. By micrometric analysis it was found that in the case of the unveined hornblende-schist from Waterton the ratio of the light and dark was about 1 : 2. Thus there is now about four times as much of the light as before and new material makes up about one-half of the total volume of the rock, as at West Kinharrachie. A still higher proportion appears in later pseudo-dioritic stages.

Stage 4 veining is relatively localized so that 1-in. bands of the new coarse-grained rocks often alternate with thicker layers representing all the previous varieties back to stage 0. To account for this compound type, which in the field has a most striking appearance, it does not seem necessary to postulate more than one period of the movements which would be the essential counterparts of injection.

The less affected layers are continuous as far as foliation allows them to be traced, so that the entire injection at this stage is of a lit-par-lit type, taking place no doubt under the influence of external forces. These forces, however, induced no more than a gentle plastic flow, and little displacement of the hornblendic bands took place. Often transverse veins spread out laterally into patches and become hornblendic. It is evident that the veinstuff was of such a composition that under applied pressure it reacted to a considerable extent with

the hornblendic material in its path. If this reaction did not actually cause solution or liquefaction at least it entailed a process of permeation and mixing. Only in this way is it possible to explain the selective omission of the intervening layers which escaped infiltration and therefore suffered no reconstitution. This argument finds support when the next stage is considered.

Stage 5. *New Matrix: Rounded Enclaves: often Fluxional*

Stage 5 is clearly more advanced, for here the unaffected portions are in isolated patches and appear as separate enclaves. The coalescence of the veins and the incorporation within them of the basic country-rock have led to the formation of a pseudo-dioritic matrix. Permeation has been more widespread than in the previous stage and coarse recrystallized rock surrounds sub-angular inclusions of the parental hornblende-schist. These average about 1 cubic inch in volume, but may reach 50 cubic inches. They are only occasionally arranged so that their planes of schistosity conform to the foliation imposed on the matrix. Stage 5 in its extreme form shows the diversely oriented enclaves set in a hornblendic complex which has lost all foliation. There is a textural transition from gneissic to plutonic varieties. Many excellent exposures of these advanced forms may be seen in the coppices south-east of West Kinharrachie and the mineral grains are sufficiently large to be identified by the naked eye. They include quartz, andesine, large hornblende prisms, and biotite plates. The enclaves are sometimes transformed into compact hornfelses. Without the enclaves the rock looks like perfectly straightforward diorite.

In summary, the veins range, first, from occasional fine strings (stage 1), to an ubiquitous filtrate (stage 2), and substantial segregations (stage 3) and, then, during recrystallization, from distinct layers (stage 4) to an all-enclosing medium (stage 5).

Various phenomena associated with stage 5 include the penetration of S-planes in the schist enclaves by white veins from the enclosing matrix. There is, too, a considerable degree of rounding and the inclusions become ellipsoidal. The whole process of conversion from meta-dolerite to pseudo-diorite is entirely progressive.

Stage 6. *Relics of Schist: Finally Homogeneous—a Dioritic Type*

The size and number of inclusions in the Kinharrachie Type decreases until in stage 6 an apparently homogeneous pseudo-diorite or diorite is formed. This rock is completely recrystallized. Only small areas upstream from West Kinharrachie show this extreme form, which is similar in texture and composition to the matrix in stage 5. Hornblende-bearing veins pass imperceptibly into the hornblendic complex. Often the rock is of normal igneous aspect but sometimes dark hornblende

or biotite streaks, representing relict enclaves, are visible. Whenever fluxion is present it also is expressed by filmy aggregates of hornblende and biotite.

The matrix of the pseudo-diorite of stages 5 and 6 is a coarse, rarely fluxional, hornblende-plagioclase rock. Large plates of hornblende are the chief constituents, pleochroic from yellow-green to deep green, and often sieved by small grains of andesine. Subhedra of lamellar-twinned andesine, generally fresh but sometimes sericitized and with patchy extinction, are scattered through the non-fluxional varieties. Granular quartz, bleached biotite, and pyroxene occur in smaller quantities, with zircon, sphene, epidote, and magnetite as the accessories. Text-fig. 2c shows the appearance of the matrix in thin section.

When the hornblende-schists of the country-rocks occur as enclaves in the migmatites they generally contain more biotite than the normal hornblende-schist. Both hornblende and biotite appear in large plates, often interlaminated with, or surrounding, granular associations of quartz and feldspar. The quartz is mostly in elongated aggregates and the feldspars are medium andesine. The hornblendes poikiloblastically include quartz and feldspar grains. Iron ores and apatite are quite common in small amounts. Hypersthene may replace hornblende, but monoclinic pyroxene has not been observed.

III. Chemical Analyses and Discussion

Two rocks of the Kinharrachie series have been analysed, the first an unmodified hornblende-schist from Waterton and the second a hornblende-migmatite or pseudo-diorite of stage 6 from West Kinharrachie. These analyses, with others for comparison, are given in the Table overleaf. The epidiorite from Portsoy, like the hornblende-schist from Waterton, belongs to a phase of basic igneous activity which preceded the regional metamorphism.

The two Ellon analyses are compared by Niggli values, also in the Table. The chief changes on migmatization appear to be an increase in silica and alkalis, especially soda. The leucocratic patches and veins, whatever may be the process of their formation, are clearly of trondhjemitic affinities. The addition of such material results in the formation of pseudo-diorite from the meta-dolerite.

The Kinharrachie pseudo-diorite is remarkably similar in composition to certain diorites of hybrid origin, including those of the Central Ring Complex in Arran and the Creag Strollamus area in Skye (both in the Table overleaf). In Arran " the petrographic evidence renders it probable that the pure homogeneous diorite and quartz-diorite are the final results of the complete solution of gabbroidal rocks within the granitic magma " (Tyrrell, 1928, p. 172). Both in Arran and at Kinharrachie all stages in the contamination process can

TABLE OF ANALYSES

	1	2	3	4	5	6
SiO_2	46·58	55·42	48·65	53·67	55·64	56·77
Al_2O_3	17·52	14·94	14·92	15·47	16·72	16·67
Fe_2O_3	0·59	2·89	1·31	3·24	1·88	3·16
FeO	8·48	7·63	8·03	7·25	7·60	4·40
MgO	10·58	6·02	8·92	4·90	3·40	4·17
CaO	11·86	7·45	8·79	8·28	6·82	6·74
Na_2O	1·92	2·68	2·56	2·77	3·85	3·39
K_2O	0·48	0·88	1·76	0·80	1·34	2·12
H_2O+	0·93	0·57	1·26	0·23	1·27	1·36
H_2O-	0·26	0·12	0·23	1·73	0·38	
TiO_2	0·32	0·78	1·30	1·28	1·02	0·84
P_2O_5	trace	0·08	0·17	0·21	0·09	0·25
MnO	0·27	0·25	0·11	0·31	0·18	0·13
CO_2	nil	nil	0·96	0·04	nil	—
Fe_7S_8	—	—	1·07	—	—	—
etc.	—	—	—	0·08	—	—
	99·79	99·71	100·04	100·26	100·19	100·00

NIGGLI VALUES

	si	*al*	*fm*	*c*	*alk*	*k*	*mg*	*c/fm*
1. Amphibole-schist	95	21	48·4	26	4·4	0·14	0·67	0·54
2. Pseudo-diorite	147	23	47·0	21	8·4	0·17	0·51	0·45

1. Amphibole-schist. 150 yards S. of Waterton, Ellon. Analyst: W. H. Herdsman.
2. Pseudo-diorite. Centre of Craigouthorn Wood, West Kinharrachie, near Ellon. Analyst: W. H. Herdsman.
3. Epidiorite. Sea-cliff, 70 yards W. of Gasworks, Portsoy, Banffshire. Analyst: E. G. Radley. (Read, 1923B, p. 93.)
4. Diorite Central Ring Complex, quarry at bridge over Allt nan Calaman, at roadside, Gleann an t-Suidhe, Arran. Analyst: E. G. Radley. (Tyrrell, 1928, p. 192.)
5. Acidified gabbro. Northern slopes of Creag Strollamus. Analyst: W. H. Herdsman. (King, 1952, p. 379.)
6. Average diorite. "Igneous Rocks and the Depths of the Earth," Daly, 1935, p. 16.

be studied in the field and under the microscope. Having examined these two areas in detail, the author considers that Kinharrachie shows a fuller sequence and a wider spacing of the end members. In both areas acicular hornblendes are seen but they are better developed in Arran. Though in each case one rock partner is of gabbroidal origin, in Arran this is a quartz-gabbro with no less than 52·43 per cent silica before contamination, whereas the Aberdeenshire amphibole-schist has only 46·58 per cent. The greater basicity of the latter has perhaps induced the stronger reaction observed above.

In Glen Dessarry diorites have been "formed by the incorporation of pyroxene-amphibole rocks in pegmatitic fluids" (Harry, 1951,

p. 151). Hornblende-migmatites have been recorded from North Sutherland, where a similar origin was proposed (Cheng, 1942, p. 77). The Kinharrachie hornblende-migmatites also present a close resemblance to the hornblende-complex of Cromar described by Read (1927). In Cromar there is evidence of the formation of pseudo-dioritic rocks by the mixture of acid material with hornblende-schist. The parent rock, the veins and the products all correspond at Cromar and Kinharrachie.

IV. Associated Hornblendic and Biotitic Migmatites

In the fields beside Esslemont Station, gneissose hornblende-migmatites reaching stage 5 of the Kinharrachie Type sequence may be seen. To the north and west the sedimentary Highland Schists are in an advanced state of migmatization, entirely compatible with the effects on the hornblendic rocks. Certain of the mixed rocks here are poorer in hornblende than the usual dioritic type, but they are correspondingly richer in quartz, feldspar, and biotite.

This example will serve as an introduction to another factor in the evolution of certain petrogenetic types. In the more advanced stages of migmatization at Esslemont the vein material probably mixed simultaneously with juxtaposed hornblende-schists and mica-schists. In the less advanced stages, however, no such three-cornered mixing has taken place and the acid strings have simply invaded both types in situ, a circumstance which may be examined in the outer zone of the series of exposures centred on West Kinharrachie. Hornblende-schists and biotite-schists occur together by the roadside 300 yards W.S.W. of East Kinharrachie. Both types are cut almost equally by quartz-feldspar veins and the original foliation is maintained. In the woods upstream the hornblendic mixtures pass into quartz-feldspar-biotite rocks resembling a non-cordierite-bearing Arnage Type (Read and Farquhar, 1952b, pp. 425–8). Still further north-westwards the dominant rock is a genuine Arnage Type though here too there are hornblende lenticles.

The railway cutting south of Little Arnage provides a section in an alternating series of hornblende-schists and biotite-gneisses, which have both been migmatized to varying degrees. Where mixing has been of sufficient magnitude to merge the two country-rocks any new rock types produced from such a triple origin lose their value as zonal indicators in the migmatite series. The railway cutting in the rocks concerned starts at a point half a mile north of Ellon Station and continues for over a mile almost to the norite of Little Arnage. The traverse begins with hornblende-schists cut by a few acid veins (up to stages 2 and 3), found both in the railway cutting and in the laneside 50 yards east of the first bridge. In a clump of trees west of

the railway and near this lane, hornblendic stage 2 is found in association with hornblende-biotite-gneisses. Northwards the veins broaden and coalesce: the rock assumes a xenolithic aspect. The rather rounded fragments (stages 4 and 5) are not in fact xenoliths, but are purely the unaltered relics of the much-veined rock. This type is best seen in the cutting west of Cookston and in half a dozen fields nearby. Cordierite-quartz-feldspar-biotite-garnet rocks of Arnage Type are also found, emphasizing the local nature of the hornblendic bands. Country-rock still predominates but is much contaminated and the amount of igneous material may be observed to have increased as compared with that at the beginning of the section. Mixtures of the hornblende-schists and biotite-gneisses also occur on either side of the platelayers' hut in the deep cutting W.N.W. of Cookston, but the contaminated rocks are here engulfed by later norite in unaltered veins.

With the addition of biotitic material as a third component in dioritic development, a gradation between the Kinharrachie and the other migmatitic types makes its appearance.

ACKNOWLEDGMENTS

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"Hutton's Unconformity," Isle of Arran

By S. I. Tomkeieff

Abstract

It is shown that "Hutton's Unconformity" on the Isle of Arran has been misinterpreted. The assumed plane of unconformity is in reality the plane separating the Dalradian schists from the uppermost zone of schists impregnated with and cemented by calcareous material. The true plane of unconformity is situated some 4 feet above this plane.

"HUTTON'S Unconformity" on the Isle of Arran is a geological monument of great historical importance. It was discovered by James Hutton in the summer of 1787 and it was the first of three such discoveries which he made, the others being at Jedburgh and Siccar Point. The three together provided him with valuable evidence in support of his "geostrophic cycle"—the theory which can now be regarded as the backbone of the modern science of geology.

Long before his visit to Arran in 1787 Hutton was aware that both the Highland Schists and the Greywacke of the Southern Uplands of Scotland (both of them included under the name "Alpine Schistus") were strongly folded and often perpendicular or steeply inclined, while the softer sandstones, shales, and limestones found in the Midland Valley of Scotland (called by Hutton "secondary or low country strata") were usually only gently folded. Hutton's theory postulated a period or periods in the history of the earth during which stratified rocks were folded, denuded, and eventually overlain by the next set of sediments. Thus the finding of the junction between the two sets of strata was for Hutton "an object which I have long looked for, I may almost say in vain" (1899, iii, 230), "and I found it, in a place where I had not thought almost of looking for it" (1899, iii, 232). This desired junction was on the shore east of Newton Point, north-east of Loch Ranza, in the northern part of the Isle of Arran.

Hutton included his full description of the geology of Arran in the third volume of the *Theory of the Earth*, the manuscript of which was lost for more than a century. It was discovered in the library of the Geological Society of London by F. D. Adams (1935), and was published in an edition by A. Geikie in 1899. Therefore the only reference by Hutton himself in his lifetime to the unconformity, which now bears his name, is that given in volume one of his *Theory of the Earth* (1795), and quoted here in full:—

> "I had long looked for the immediate junction of the secondary or low country strata with the alpine schistus, without finding it; the first place in which I observed it was at the north end of the island of Arran, at the mouth of Loch Ranza; it was upon the shore,

where the inclined strata appeared bare, being washed by the sea. It was but a very small part that I could see; but what appeared was most distinct. Here the schistus and the sandstone strata both rise inclined at an angle of about 45°; but these primary and secondary strata were inclined in almost opposite directions; and thus they met together like two sides of a *lambda*, or the rigging of a house, being a little in disorder at the angle of their junction. From this situation of those two different masses of strata, it is evidently impossible that either of them could have been formed originally in that position; therefore, I could not here learn in what state the schistus strata had been in when those of the sandstone, etc., had been superinduced " (1795, i, 429–430).

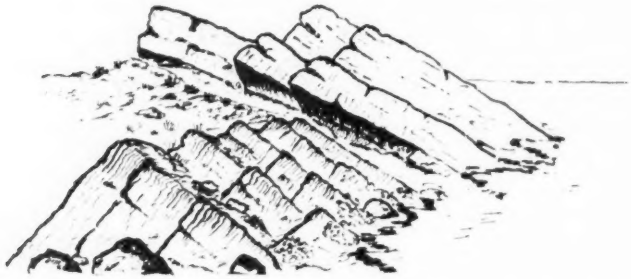
In the third volume Hutton mentions a drawing of this unconformity, but this drawing was apparently lost and has never been found. Thus the drawing in volume three of the *Theory of the Earth* is by the editor, A. Geikie (1899, iii, 235). It is important to note, that although the term " unconformity " is now freely used, neither Hutton nor his interpreter, Playfair, nor Jameson in his original description of Arran (1798, 1800) ever use this term, which was probably introduced later.

Robert Jameson who visited Arran in 1794 and on subsequent occasions followed in the footsteps of Hutton, often only to refute his genetic interpretation of observed facts. In his first book (1798) he makes only one reference to " Hutton's Unconformity "—" A few hundred yards from the entrance to the Loch, the sea has formed an interesting section of the strata, which demonstrates, in a satisfactory manner, the relative position of the sandstone, limestone, and micaceous shistus " (1798, 104). This is amplified in his second book—" The micaceous shistus which forms the shore is inclined at an angle of 45° and dips to the south-east; the secondary strata are inclined at an angle of 45°, but dips to the north-west, so that the two kinds of strata meet together similar, as Hutton remarks, to the sides of a lambda, or the roof of a house. The secondary strata are of red-coloured argillaceous sandstone (which sometimes appears passing into breccia) which alternates with limestone. This limestone sometimes contains masses of hornstone, a fact somewhat similar to the occurrence of flint in the chalk beds of England " (1800, 78).

This description is illustrated by the drawing of a section across the unconformity (1800, plate facing p. 103). Jameson's drawing is not very reliable, the basalt dyke appearing to the west of the locality, when, in fact, it is on the eastern side. It is, however, the first pictorial representation of " Hutton's Unconformity " in Arran. Hutton himself has illustrated the Jedburgh unconformity five years previously at the end of the first volume of his *Theory of the Earth* (1795, pl. iii).

Jameson, in the book in question, did not discuss the significance of the unconformity, neither did he discuss Hutton's theory bearing on this subject, but at the end of the chapter on Arran under item six of " Observations to be made ", he wrote: " To determine the direction and inclination of all the strata throughout the island; so as to know whether they have much the same general arrangement, and if they are frequently situated in a similar manner with the strata at the mouth of Loch-Ranza " (1800, 125).

Since 1800 " Hutton's Unconformity " on the Isle of Arran has been frequently mentioned by geologists, who have visited the island, but nothing new has been added to its description, except perhaps more accurate determination of the dips of the two sets of strata. In the first memoir on Arran published by the Geological Survey (Gunn,



TEXT-FIG. 1.—" Hutton's Unconformity," Isle of Arran. Sketch by M. Ash.

1903), a photograph of the " unconformability " was included (plate v, opposite p. 52), but in the second memoir (Tyrrell, 1928) this photograph did not appear. In both of these memoirs the overlying sandstones containing lenticular bands of limestone and breccia were referred to the Calciferous Sandstone division of the Carboniferous system, but on the geological map of Arran (1947) the age of these beds is given as Upper Old Red Sandstone. As, in point of fact, we have here strata belonging to the Cornstone division, the strata in question may be considered to represent the transition series between the two respective systems—Carboniferous and Old Red Sandstone.

Along the shore east of Newton Point these strata occur as very small crescent-shaped outcrop with a general dip to the north-west at an angle of about 25°. These beds rest unconformably on the Dalradian schists which have a general dip to the south-east or south-south-east at an angle of 45° to 65°. " Hutton's Unconformity " is situated at the eastern end of the outcrop of the Cornstone beds. Looking at it from the east (Text-fig. 1) we see in the foreground the steeply dipping Dalradian schists (inclined to the left), and in the background

the Cornstone beds dipping in the opposite direction. What appears as the lowermost bed of the Cornstone series, some 4 feet in thickness, is separated from the underlying Dalradian schists by a deep undercut gash formed through the combined action of a small stream and tides. As far as I know every geologist visiting this locality assumed this gash to be situated along the plane of the unconformity, and this is the interpretation provided by A. Geikie (Text-fig. 2A).

In April, 1949, during one of the students' geological field weeks, organized by the Geological Department of King's College, Newcastle upon Tyne, the writer's son most unexpectedly discovered that the 4 ft. bed situated immediately above the gash was neither sandstone nor limestone, but was made of Dalradian schists in continuity with the underlying schists, but completely impregnated and cemented by calcareous material. Traces of schists are clearly seen both on the sides and on the upper surface of this bed. This discovery has been

A B

TEXT-FIG. 2.—A. Section of the unconformity as given by A. Geikie (Hutton, 1899, iii, 235, fig. 8). P_1 plane of unconformity. B. A new interpretation of the unconformity. P_2 plane of unconformity.

confirmed by repeated examination of the occurrence during subsequent visits.

Hutton himself was slightly puzzled by the relation between the two sets of strata, for he wrote: " Those two different kinds of stratified bodies rise to meet each other; they are somewhat confused at the immediate junction; but some of the sandstone or calcareous strata overlap the ends of the alpine schistus " (1899, iii, 235). The sketch which he made for his book was never found and so to remedy this A. Geikie drew a section across the unconformity (1899, iii, 235, fig. 8), which is reproduced here (Text-fig. 2A). This drawing leaves no doubt where the plane of unconformity is supposed to be situated. The discovery that the bed above the gash is made of Dalradian schists cemented by calcareous matter, suggests that the plane of unconformity is actually situated some 4 feet above the gash and below the overlying sandstone bed, as indicated in Text-fig. 2B (plane P_2 instead of plane P_1). This relation is found only in the eastern end of the outcrop, as towards the west the gash extends in such a way as to cut above the cemented top of the Dalradian schists. In Text-fig. 1 the outcrop of the overlying

strata situated to the extreme left is made of sandstone immediately above the unconformity.

One must also conclude that the bed between planes P_1 and P_2 (Text-fig. 2B) represents the uppermost zone of the Dalradian schists platform, impregnated and cemented by calcareous material, probably derived from the calcareous ooze solutions present at the bottom of the sea during the Cornstones period of sedimentation. This impregnated and cemented zone probably offered a greater resistance to denudation than the underlying unaltered schists. This would explain the undercut gash at the base of this zone and the appearance of the pseudo-unconformity plane, which has apparently deceived all the visiting geologists for over a century and a half.

In conclusion I would like to thank my son, Mr. M. V. Tomkeieff for his help in the field, Mr. M. Ash for making a sketch of the unconformity, and Mr. J. Lee for preparing Text-fig. 2.

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Quartzite Xenoliths from the Ballachulish Granodiorite

By I. D. Muir

(PLATE XV)

Abstract

Small quartzite xenoliths scattered throughout the granodiorite are mantled by broad mafic coronas, the inner part of which is composed largely of augite and the outer part mainly of hornblende. The formation of the coronas is examined and some general features of magmatic reaction with quartzite inclusions are discussed.

I. Introduction

THE Ballachulish granodiorite is well known for the abundance of pelitic xenoliths in its coastal section. Limestone xenoliths, semi-calcareous xenoliths, and quartzite xenoliths are also found and an account of the reaction of the granodiorite with limestone inclusions has already been published (Muir, 1953). Most of the quartzite xenoliths encountered were found in the most northern of the Kentallen " Granite " quarries but others were observed occasionally at different localities throughout the north-western portion of the granodiorite.

In the field these xenoliths, which range from 2 to 9 inches in diameter, present a very striking appearance, for the white quartzite is margined by a broad mafic corona, the inner part of which is rich in pale green augite and the outer, much wider portion, greenish black in colour, is composed for the most part of hornblende (Plate XV, fig. 1). This zone resembles an appinite in appearance. The coronas, which range from a quarter to three-quarters of an inch in width, are thickest where a well defined pyroxene zone persists and in the outer part deep red crystals of sphene may be seen clearly in hand specimen. A certain amount of plagioclase and quartz occur interstitially in both zones, but orthoclase and biotite are absent except where the coronas are being disrupted by the incursion of feldspathic material. In such cases where they have been wedged apart, large clots of hornblende can be observed streaming away into the neighbouring granodiorite. Generally, however, the outer portions of the coronas effect a sharp junction with the host rock. There is little evidence that the surrounding granodiorite has assimilated any considerable amount of silica from the xenolith.

II. Petrography

(*a*) *The Granodiorite.*

The normal granodiorite of the Ballachulish Complex is a grey, medium-grained hornblende-biotite type (anal., Table 1, No. 4), in

which strongly zoned plagioclase crystals with cores (An_{38-28}), which are frequently sericitized, are often sharply mantled by fresh oligoclase (An_{24-20}). The dark minerals which may make up over 20 per cent of the rock occur mainly in small clots in which large ragged, pleochroic grains of sphene tend to be moulded on to the hornblende. Microperthite with rather fine albite spindles occurs interstitially and forms large anhedral plates up to three millimetres in diameter. It corrodes and veins the plagioclase and myrmekite is sometimes developed where the two minerals come in contact. Accessories are sphene, apatite, magnetite, pyrite, zircon, and orthite. For reasons given elsewhere (Muir, 1953), this rock is regarded as a heavily contaminated type.

(*b*) *The Xenoliths.*

The xenoliths themselves, which are rarely altered, are composed almost entirely of anhedral interlocking quartz grains about 1 cm. in diameter charged with large fluid inclusions. The only other minerals found occur in a fine-grained interstitial brown matrix, sometimes present, which appears to represent former feldspar. A little green chlorite and a few prisms of apatite were also noted and it is possible that these accessories were all original, for the felsdpar is invariably much altered whereas that introduced around the margins of the xenoliths is usually fresh. The xenoliths, because of their coarse grain-size, may have been derived from quartz veins in the Leven Schists, but Daly (1928) has remarked on the coarsening of the grain-size along certain bands of sandstone xenoliths enclosed in the Bushveld norite. He suggested that this might be due to their greater porosity and to the presence of connate water which, when superheated, would promote recrystallization. If this was the case the xenoliths might then be derived from quartzose bands in the schists. Spectrographic analysis for trace elements has revealed that all except the components of feldspar are below the limits of sensitivity.

A feature of these xenoliths is their marked resistance to alteration by the magma. In the Kentallen quarries the pelitic and semicalcareous xenoliths have been completely reconstituted whereas the quartzite inclusions have suffered little alteration. It is probable that their simple chemical composition is responsible for this. A relatively small addition of magmatic materials to argillaceous or semicalcareous xenoliths could produce a profound change in their mineral assemblage and bring them into equilibrium with the modified magma, but for quartzite all the materials except silica would have to be introduced. In the composite xenolith of Plate XV, fig. 1, the pelitic layer has been converted to a biotite-plagioclase-quartz rock, but the only alteration noticed in the quartzite portion is the incursion of a pyroxene-plagioclase reaction rim between the quartzite and the argillaceous portion

of the xenolith. Separation of the bands is probably the result of strain caused by differential thermal expansion of the two portions of the xenolith after its immersion in the magma.

(*c*) *The Coronas.*

(i) *Pyroxene Zone.*

Where a well defined pyroxene zone occurs marginally pale green

TEXT-FIG. 1.—Coronas to Quartzite Xenoliths.

(*a*) Pyroxene-rich margin to quartzite xenolith, Ballachulish.
Junction of corona with quartzite. Note inclusions of tiny apatites in the plagioclase (slightly altered) and quartz of the corona. Large fluid inclusions characterizes the quartz of the xenolith and the centres of some of the quartz grains of the corona. Some of the augite is altering to hornblende. × 30.

(*b*) Hornblende-rich zone of corona, Ballachulish.
Augite occurs only as relics enclosed in the hornblende. A large grain of sphene is seen in upper part of section. Interstitial material is composed of oligoclase and quartz. × 30.

(*c*) Junction of corona and xenolith in syenite Kangerdluarsak, near Julianehaab, South Greenland.
Rounded grains of quartz of the xenolith with tiny apatite needles enclosed by perthitic microcline. The corona consists of stumpy grains of aegirine-augite and a brown alkali amphibole set in a base of alkali feldspars and quartz with nests of tiny apatite needles. × 25.

augite and sodic oligoclase are the two minerals which are directly in contact with the xenolith. The plagioclase (An_{15}) which is practically unzoned seems to be penetrating the quartz along grain junctions and may enclose a few rounded remnants of it. It usually contains swarms of tiny apatite crystals, is generally clear and fresh, and has a tendency to form large poikilitic plates enclosing the augite. Quartz, occurring as irregular patches enclosed in or wedged between the other minerals, may enclose crystals of augite. The quartz grains of the corona are

TABLE I.—ANALYSES OF ROCKS

	I.	II.	A.	III.	IV.
SiO_2	59·94	59·43	57·80	62·53	59·11
Al_2O_3	5·04	5·54	8·76	16·49	17·85
Fe_2O_3	2·00	4·63	3·27	1·82	1·78
FeO	4·97	7·08	5·41	2·99	3·24
MgO	8·30	7·89	9·80	2·80	3·85
CaO	14·72	9·05	8·05	4·78	5·05
Na_2O	1·87	1·65	3·02	4·17	4·10
K_2O	0·14	0·58	2·01	2·12	3·06
H_2O+	0·57	1·23	0·63	0·67	0·73
H_2O-	0·22	0·16	0·13	0·16	0·11
F_2	n.d.	0·30[1]	n.d.	n.d.	n.d.
P_2O_5	1·06	1·32	0·14	0·63	0·14
TiO_2	0·40	1·42	0·83	0·74	0·30
MnO	0·27	0·26	0·11	0·07	0·05
BaO	nil			0·13	0·23*
S	n.d.			0·25	0·19
	99·50	100·54	99·96	100·35	99·79
		0·14		0·12	0·09
	99·50	100·40	99·96	100·23	99·70
MOLECULAR RATIOS					
$\frac{Fe'' + Fe'''}{Mg}$	0·36	0·65	0·26	0·76	0·58

seldom more than half a millimetre in diameter, contain nests of tiny needles of apatite, and their centres only are charged with large fluid inclusions. Apatite, occurring mainly as the slender little needles so characteristic of many contaminated rocks, is enclosed mainly in the leucocratic constituents (Text-fig. 1*a*).

The augite tends to build small, discrete, stout, euhedral prisms from a quarter to half a millimetre in length where it adjoins the quartz. The earliest augite, i.e. that nearest to the xenoliths ($\alpha = 1{\cdot}684$, $\gamma = 1{\cdot}710$) is very pale in colour but the later pyroxene which occurs as larger grains up to 1½ millimetres in length or marginally to the pale variety, is deeper in colour and has slightly higher refractive indices ($\alpha = 1{\cdot}689$, $\gamma = 1{\cdot}715$). Some is beginning to alter to hornblende along the cleavages and the final product is a crystal of green hornblende enclosing a residual core of augite. An analysis of the augite is given in Table II, No. 1. As it was not possible to separate the two varieties, the analysis represents the composite material. No iron ore is present in this part of the corona. An analysis of the zone is given in Table I, No. 1. Significant features are the very low values of alumina and potash. Mineralogically these are expressed by the absence of orthoclase and biotite. From the textures at the contact, augite does

[1] Spectrographic determination.

NORMS

	I.	II.	A.	III.	IV.
Q	17·70	23·22	6·06	15·72	5·70
Or	0·86	3·34	11·68	12·23	18·35
Ab	15·72	14·15	25·15	35·63	34·58
An	5·00	5·84	4·73	20·02	21·13
Di Wo	25·40	12·88	13·69	0·12	1·28
Di En	17·30	8·80	11·60	0·06	0·80
Di Fs	6·07	3·04	1·95	0·06	0·40
Hy En	3·50	10·90	14·87	6·96	8·80
Hy Fs	1·19	4·36	2·56	2·98	4·49
Mt	3·02	6·73	4·87	2·55	2·55
Il	0·76	2·74	1·52	1·37	0·61
Ap	2·69	3·02	0·34	1·34	0·34
Py				0·34	0·26

MODES

Q	18·9[1]	24·0[1]	18·5	19·3	10·5
Or	1·0	1·3	14·6	7·5	10·6
Plag	15·2	11·2	7·5	49·7	48·7
Hornblende		53·0	59·4	10·2	14·4
Biotite				10·0	15·6
Augite	62·3				
Acc.	2·6	10·5		3·3	0·8

I. Clinopyroxene-rich zone—inner corona to xenolith of Plate XV, fig. 1. Kentallen Quarries.
II. Hornblende-rich zone—outer part of corona to same xenolith.
A. Quartz-orthoclase-appinite, Glen Tilt (Deer, 1950, p. 186, No. 3).
III. Modified granodiorite 2 in. from outer limit of corona.
IV. Normal granodiorite of Ballachulish Complex. Beinn a Bhaithe Bheithe (Muir, 1953, Table I, No. VI).

Analyses: I, II, III, and IV by I. D. Muir.

not appear to be replacing the quartz of the xenolith but rather seems to have separated out from the magma. The plagioclase also appears to be magmatic but it may perhaps have replaced some quartz grains at the junction with the xenolith to a minor extent.

(ii) *Hornblende Zone.*

Here the feldspar is more basic, averaging An_{22} in composition but is zoned from An_{27-18}. It occurs in large plates up to 3 millimetres across, encloses all the other minerals and is still characterized by the presence of numerous small apatites although these are not as abundant as those enclosed in the quartz. Any augite present at this stage forms cores to the green hornblende, which is the most abundant mineral of the zone (Text-fig. 1*b*). The amphibole (anal., Table II, No. 3) tends to build long prismatic crystals which are usually poorly terminated. It is a yellow-green hornblende which is sometimes fringed by an apple-green variety. Numerous inclusions of apatite and sphene occur in the amphibole, and iron ore tends to form in clusters of

[1] Calculated from analysis

rounded grains enclosed in or forming around it. At this stage sphene makes its appearance as large ragged, moderately-pleochroic, yellowish-brown grains wrapped around the augite or associated with the hornblende, and containing stout apatite inclusions. A little accessory zircon is present and apatite, now occurring principally as stout prisms has increased in amount. A little interstitial pennine and calcite are also found.

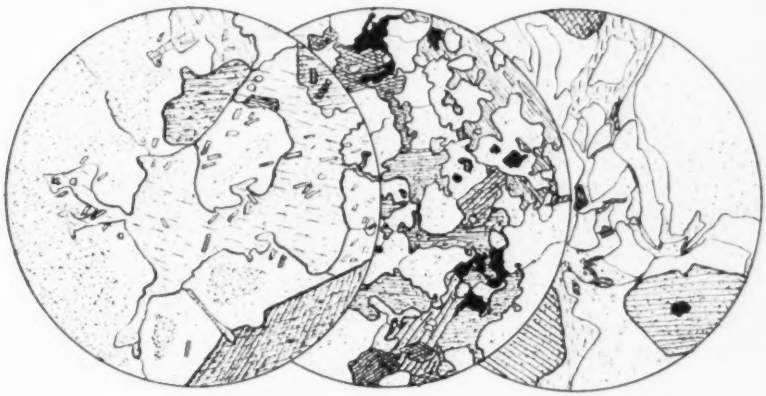
In the outer part of the hornblende zone there is a tendency for the amphibole to occur in clots of small interlocking grains associated with iron ores and chlorite, rather than as large idiomorphic crystals. This texture may perhaps be due to the complete replacement of the pyroxene, for the amphibole of such areas is always associated with little blebs of quartz. In these clots the hornblende appears sometimes to be replaced by chlorite, a change which is accompanied by the excretion of ilmenite either as sagenitic webs or as tiny irregular clusters of grains. Elsewhere, the amphibole may be mantled by the apple-green variety which is always accompanied by small sphenes. A frequent accessory mineral in the outermost part of the rim is orthite which occurs as large euhedral, reddish-brown, zoned crystals up to one millimetre in diameter. The sphenes occurring in this part of the corona are deeper in colour and more pleochroic than those described above. Plagioclase, now zoned from An_{32-21} tends to become more basic towards the outer part of the rim. All these minerals are set in a base composed of large euhedral quartz grains and stout prisms of apatite. Biotite, usually altering to chlorite, and potash feldspar have formed at a very late stage and the latter corrodes and penetrates the quartz grains whenever the two come into contact.

(*d*) *Further Alteration of the Xenoliths.*

Around other xenoliths more advanced stages of reaction may be observed. At first the minerals and textures characterizing the outer part of the rim appear progressively further inwards, but at a later stage a somewhat pegmatitic leucocratic zone, rich in pinkish feldspar and hornblende, is developed on the inner side of the mafic border. Under the microscope, this zone, which may reach half an inch in width is seen to be composed of euhedral, multiply-twinned acicular crystals of apple-green hornblende set in a base of oligoclase, orthoclase, and quartz.

The margins of the xenoliths have now become somewhat embayed and lobes of albite-oligoclase have penetrated along the intergranular boundaries. These lobes which tend to become enlarged and rounded at their ends (Text-fig. 2*a*) have replaced the quartz to some extent, but the dislodged portions of quartz grains only rarely retain the same

orientation as the remainder. Therefore it is probable that disruption of the margin of the xenolith has been achieved more by the wedging in of sodic plagioclase along grain junctions and fractures than by direct replacement of the quartz. In some cases potash feldspar too, may be observed penetrating the xenolith, but it is not restricted to grain boundaries and fractures, and rounded inclusions of quartz enclosed in this mineral retain the same orientation as the rest of the



TEXT-FIG. 2.—Replacement Structures in Quartzite Xenoliths.

(*a*) Embayed margin to quartzite xenolith showing the quartz cleared of fluid inclusions in the vicinity of lobes of albite-oligoclase which advances mostly along intergranular boundaries. Nests of little apatite needles in feldspar and in the cleared portions of the quartz. × 30.

(*b*) Replacement of quartz in xenolith by spongy crystals of hornblende. Quartz has lost its fluid inclusions and recrystallized as a mosaic of small equidimensional grains. × 30.

(*c*) "Replacement Zone" inside early corona to quartzite xenolith. A single large quartz grain forming the upper part of the field is dissected by thin veins of fresh potash feldspar (fine stippling) also forming a single crystal. Elsewhere euhedral hornblende and sericitized albite-oligoclase (stippled and dashed) occur. × 30.

grain. Replacement of the quartz may therefore be accepted for the potash feldspar. Direct replacement of the xenolith itself by hornblende is uncommon but where it does occur the quartz first loses its fluid inclusions and appears to recrystallize to a mosaic of smaller equidimensional grains not uncommonly carrying a few tiny needles of aptite (Text-fig. 2*b*).

The area between the advancing oligoclase lobes and the relic of the corona consists mainly of numerous quartz grains of varying size (which must be considered as having been separated from the xenolith

TABLE II.—MINERAL ANALYSES

	I.	II.	III.	IV.
SiO_2	49·71	51·61	46·30	45·15
Al_2O_3	2·85	2·18	8·60	8·10
TiO_2	0·34	0·28	1·03	1·25
Fe_2O_3	2·76	1·04	2·78	2·10
FeO	7·45	9·28	10·16	12·97
MgO	13·35	11·29	13·15	13·30
MnO	0·50	0·51	0·43	0·45
CaO	22·36	22·86	13·55	12·84
Na_2O	0·60	0·43	1·05	0·66
K_2O	0·04	0·07	0·48	0·32
H_2O+	0·16	0·16	1·95	2·20
H_2O-	0·13	0·14	0·18	0·20
F_2	n.d.	n.d.	0·40[1]	n.d.
	100·25	99·85	100·06	99·54
Less O for F			0·17	
	100·25	99·85	99·89	99·54
MOLECULAR RATIOS				
$\frac{Fe'' + Fe'''}{Mg}$	0·34	0·48	0·49	0·58

by the processes just described), sodic oligoclase, non-perthitic orthoclase, and euhedral apple-green hornblende. Most of these quartz grains have recrystallized and lost their fluid inclusions and many have been partly replaced by the potash feldspar (Text-fig. 2*c*). Acid oligoclase and acicular needles of hornblende are seen cutting across quartz grains in this area and they may have replaced the quartz grains directly, although inclusions of quartz in the amphibole only rarely retain the same orientation as the surrounding quartz grain. In many cases the quartz appears to have reformed after the hornblende had crystallized and some may perhaps have been redeposited from the interstitial liquid. Accessories in this " replacement zone " are strings of tiny apatite needles, a few euhedral zircons, grains of iron ore and occasional large euhedral zoned crystals of orthite. Further out, relics of pyroxene mantled by hornblende appear and these probably mark the position of the original corona to the xenolith, for inside it crystals of pyroxene and sphene are rare.

(*e*) *The Disruption of the Coronas.*

The breaking up of the mafic borders themselves is achieved partly by the enlarging of the inner feldspathic zone in which the plagioclase is frequently serecitized (a feature which can always be observed just beyond the outer limit of the coronas), and partly by an increase in the potash feldspar which corrodes and replaces the quartz. Finally,

[1] Spectrographic determination.

STRUCTURAL FORMULAE

	On basis of 6 (O, OH).		On basis of 24 (O, OH).	
	I.	II.	III.	IV.
Si	1·874	1·950	6·832	6·705
Al	·122	·050	1·168	1·295
Al	—	·050	·318	·116
Ti	·018	·009	·116	·129
Fe‴	·082	·027	·318	·232
Fe″	·235	·292	1·248	1·571
Mg	·753	·639	2·912	2·973
Mn	·016	·015	·063	·064
Ca	·899	·923	2·142	2·045
Na	·045	·030	·301	·196
K		·005	·088	·024
z	1·996	2·000	8·000	8·000
Y			4·975	5·045
X	2·048	1·990	2·531	2·265
(OH + F)			2·124	2·000

OPTICAL PROPERTIES

α	1·684–89	1·692	1·651	1·652
β	1·689–95	1·700	1·664	1·665
γ	1·711–15	1·719	1·672	1·673
2V	55°	56°	67°	69°
$\gamma \wedge c$	43·5°	45°	25°	22°
Pleochroism X	very pale green	very pale green	pale yellow	pale yellow
Y	pale green (weak)	pale green	weak olive green	olive green
Z	pale green	pale green	green	green
	Z = Y > X	Z > Y > X	Y > Z > X	Y > Z > X

I. Augite from inner zone of corona to quartzite xenolith, Kentallen Quarries.
II. Augite from augite syenite, Kentallen (Muir, 1953, Table II).
III. Hornblende from outer zone of corona to quartzite xenolith, Kentallen Quarries.
IV. Hornblende from Ballachulish granodiorite, Beinn a Bhaithe Bheithe.
All analyses by I. D. Muir.

biotite makes its appearance, and feldspathic material crystallizing out interstitially between the hornblende crystals forces them apart and thereby disperses the corona.

In a few of the partly dispersed coronas, patches of pyrites occur and kelyphitic borders to this may sometimes be observed. The normal ore was found to be slightly cupriferous and when this is margined by hornblende it tends to develop a border composed of magnetite with patches of chalcopyrite. A late stage hydrothermal reaction of this type is suggested:—

$$4FeS_2 + Cu + 4\,H_2O \rightleftharpoons Fe_3O_4 + CuFeS_2 + 6S + 4H_2$$

At the junction with these patches of ore the amphibole is usually bleached or has recrystallized to little pale acicular needles with a lower extinction angle ($\gamma \wedge c = 19°$). It is normally associated with patches of green chlorite.

(f) The Modified Granodiorite.

For a few inches beyond the limit of the coronas, the quartz content of the granodiorite is increased to as much as 20 per cent and potash feldspar is reduced in amount. Biotite is the most abundant ferromagnesian mineral and the primary (as distinct from xenocrystal) hornblende is an apple-green variety. Clots of yellow-green hornblende with pyroxene cores, and large crystals of sphene with accessory ilmenite and chlorite are quite common and are obviously derived from the coronas. Plagioclase occurs as hypidiomorphic laths zoned from $An_{(32-20)}$ and the interstitial potash feldspar corroding and veining the plagioclase, is only very feebly microperthitic. This may perhaps be correlated with the increased amount of soda from the magma required to form the more acid plagioclase around the xenoliths (cf. Nockolds, 1933). Some of the quartz in the modified granodiorite appears to have been mechanically derived from the coronas for it has the large inclusions in the centres of the grains and the little nests of apatite needles described earlier. Most of the quartz, however, is free from these characters and must have crystallized directly from the magma. This quartz is moulded on to all the other constituents except potash feldspar.

In order to try and distinguish between the different types of quartz present in the xenoliths, coronas, replacement zones, and the normal and modified varieties of the granodiorite, powder photographs of seven quartz samples were kindly taken by Mr. K. Rickson with a 19 cm. camera. 2θ values for the (234) line (Tuttle and Keith, 1952) were measured and are given in Table III but it is clear that there is no

TABLE III.—VARIATION IN 2θ FOR 234 LINE OF QUARTZ

($Cu\ K\alpha_1$)

Specimen	2θ
Xenoliths	
1	153·600°
2	153·608°
Replacement Zone of 1	153·560°
Pyroxene Zone of corona of 2	153·658°
Hornblende Zone of corona of 2	153·572°
Modified granodiorite	153·730°
Normal granodiorite	153·596°

Accuracy ± ·150°

systematic variation in the position of this line which can be detected within the limits of accuracy of the method.

The analysis of the modified granodiorite is given in Table I, No. 3. The reduction in potash feldspar is accounted for partly by the hornblende-biotite reaction which would reduce the amount of potash and alumina available from the magma. With increased silica, the place of the yellow-green hornblende has been taken by the apple-green variety and conditions locally appear to have required a mineral association similar to that of the adamellite which forms the latest major intrusion of the Ballachulish Complex. Here the stable ferromagnesian minerals are a more iron-rich biotite and a little apple-green hornblende.

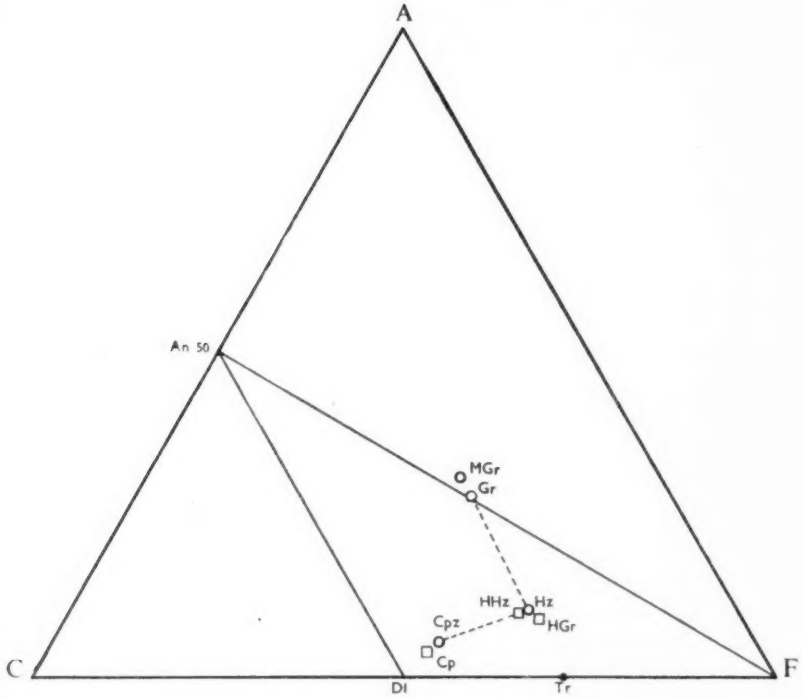
Both the chemical analysis and mode of the modified granodiorite show it to be somewhat richer in silica than the normal rock of this part of the complex and when the analyses are plotted on an A C F diagram (Text-fig. 3), the modified and normal granodiorites and the hornblendic zone of the corona lie in a straight line. This would suggest that the increased silica content of the modified granodiorite was due rather to the withdrawal of the mafic constituents to form the coronas than to the addition of silica from the xenoliths. It is probable therefore that much of the silica lost by the xenoliths has reformed in the two zones of the corona.

III. Discussion

The rounded nature of the xenoliths against which pale green augite crystallized indicates that as the pyroxene was forming some of the quartz was being taken into solution. In no case is there any evidence of the pyroxene replacing the quartz. Further away from the xenolith as more augite crystallized it became deeper in colour, and at a still later stage its place was taken by hornblende. Later still, hornblende was joined by sphene and magnetite. The plagioclase of the corona becomes more sodic as it approaches the xenolith, ranging from zoned crystals (An_{27-18}) at the outer edge to a uniform An_{15} in the pyroxene zone. It is of later formation than the ferromagnesian minerals.

At this early stage little replacement of the quartz of the xenolith can be detected, but possibly a little replacement by albite—oligoclase may have taken place along the margins and at grain junctions. Later an inner feldspathic zone appears inside the corona, and in this area, where potash feldspar is found for the first time as a major constituent, replacement of quartz grains can definitely be established. The commonest replacement is by potash feldspar but plagioclase and to some extent hornblende seem to have formed in place of the quartz as well, although the feldspar-forming materials generally seem to have advanced further into the quartzite than the ferro-

magnesians. The presence of the hornblende rim to the xenoliths can be explained by the crystallization of the phase with which the magma was saturated to provide heat for solution of the quartz (Bowen, 1928), but the formation of an inner augite corona is difficult



TEXT-FIG. 3.

Ballachulish, ACF Plot of quartzite—granodiorite contamination.

○ Rocks.
□ Minerals

MGr	Modified granodiorite.
Gr	Normal granodiorite.
Hz	Hornblende zone of corona.
Cpz	Clinopyroxene zone of corona.
Cp	Clinopyroxene of corona.
HHz	Hornblende of hornblende zone.
HGr	Hornblende of normal granodiorite.

to understand. In acid magmas the crystallization of pyroxenes rather than amphiboles as a result of contamination, is seen where alkaline rocks are developed locally by reaction with limestones. Here the relative loss of alumina by the magma with respect to alkalies has

suppressed the formation of the aluminous minerals hornblende and biotite. In the potassic syenite modification produced locally in the granodiorite of Ballachulish (Muir, 1953) variation of the alkali-alumina ratio has produced a pyroxene (anal., Table II, No. 2) whose composition apart from the ratio of Fe''' to Fe'' is similar to that formed around the quartzite xenoliths. The augite of the corona (Table II, No. 1) is somewhat lower in silica. It has no alumina present in the *Y* group and since sodium is quite low, aluminium in the *Z* group is balanced mainly by ferric iron. As would be expected from its appearance in the granodiorite, it is more iron-rich than normal Caledonian augites but is also somewhat richer in lime.

Clearly the addition of silica alone to a magma without any concurrent transfer of the other bases to the xenoliths could not of itself effect an alteration of the alkali-alumina or alkali-lime, magnesia or ferrous oxide ratios and thereby lead to the formation of a clinopyroxene. The separation of augite and a more sodic plagioclase, rather than hornblende, biotite, and andesine would tend to enrich the liquid relatively with alumina and little alteration could be expected in the alumina-silica ratio. Reduction of this ratio is unlikely to be the cause of the production of augite for pyroxenes are not the normal ferromagnesian minerals of the most acid plutonic rocks.

In view of the contaminated nature of the granodiorite the possibility of the xenoliths with their pyroxene coronas being relics of reaction with an earlier igneous rock must be considered. If this was the case more calcic plagioclase should be formed in the inner zone of the corona, but it is never present and in the Kentallen quarries where most of the xenoliths are found, no earlier igneous xenoliths are encountered.

It would appear then, that a pyroxene corona was formed around the xenolith in the granodiorite at a very early stage either as a metastable reaction product as a result of deficiency of volatiles, or as the normal earliest crystallizing mineral of a rather basic granodiorite. The sodic plagioclase which is the other major magmatic constituent of the inner corona is of later formation and probably formed from a silica-enriched liquid. The production of the thick outer hornblende zone enclosing the pyroxene would tend to protect it from reaction with the magma so that the pyroxenes formed around the xenoliths would be preserved whereas if any were formed elsewhere they would now be completely absorbed and their place taken by hornblende.

The hornblende of the outer corona (anal., Table II, No. 3) differs from that of the granodiorite (anal., Table II, No. 4) in having a somewhat higher silica and lime and lower iron content. The higher lime is not due to any pyroxene or apatite contamination in the

analysed material but might be regarded rather as an expression of the hornblende having been derived to some extent by replacement of pyroxene. It lies in the field of hornblendes from normal diorites and granodiorites (Nockolds and Mitchell, 1948). Associated with the formation of hornblende in the outer zone of the corona is the appearance of large pleochroic grains of sphene. As biotite was not able to crystallize during the formation of the coronas (the biotite of the granodiorite contains about 3 per cent TiO_2) and as both the augite and the hornblende have lower titania contents than the mica, the titania available from the magma appears to have combined with lime released by the augite-hornblende reaction and formed sphene, for it is significant that large sphenes are absent from the rims in regions poor in hornblende and that much of the hornblende with which they are associated has been produced by alteration of the augite. It is possible also that some of the lime released would go to the formation of the large apatites associated with the hornblende.

The high content of titania and phosphorus in the coronas, the high Fe'''/Fe'' ratio, and the coarse grain-size of the minerals, suggests that a concentration of the volatile constituents of the magma was effected around the xenoliths during the formation of the later stages of the coronas. The piling up of volatile constituents as apatite and sphene in xenoliths is now well known but is unusual for them to be concentrated around the xenolith margins. A possible explanation might be that TiO_2 and P_2O_5 would tend to enter the xenolith in quantity only if there was some element, e.g. calcium already there with which they could combine. Similar concentrations of titania as sphene have been described by Wells (1951) from the hypersthene gabbro of Ardnamurchan where a clinopyroxene corona has been developed marginally to siliceous xenoliths.

The low potash contents of both zones of the corona can probably be understood as far as the leucocratic constituents are concerned from a consideration of the granite cotectic curve (Nockolds, 1947). The addition of silica to a granodiorite liquid would result in the crystallization of plagioclase alone at first until the plagioclase-quartz boundary was reached when it would be joined by quartz. Potash feldspar could not separate until the composition of the liquid reached the ternary cotectic curve. Hence, in the coronas, formed from the relatively early crystallizing constituents of the magma, potash feldspar is lacking.

Only in the latest stages have conditions permitted the formation of biotite and potash feldspar. The production of these minerals and the reduction of sphene in the outermost parts of the rims and in the wedges of magmatic material which have assisted in their final disruption,

indicates a return to the original conditions. The low potash content noted both in these wedges and in the modified granodiorite is difficult to explain, but it is possible that the potash-rich residuum would migrate back into the less modified liquid. The alteration of hornblende to chlorite and ilmenite in the outer art of the rim is attributed to hydrothermal alteration subsequent to the crystallization of the surrounding granodiorite. Lime released in this process could enter calcite, which occurs only in the outermost parts of the coronas where hornblende has been replaced.

IV. Comparisons and Conclusions

Mafic fringes to inclusions of quartzite were first recorded by Lacroix (1893) who described many examples from volcanic rocks. In nearly all cases the characteristic ferromagnesian mineral produced was augite but most of the recorded instances of corona formation come from basic rocks where augite was the normal ferromagnesian mineral. Such fringes have been described from Mull by Thomas (1922), from the upper part of the Ben Hiant intrusion in Ardnamurchan (Richey and Thomas, 1930), from sills in the Moeraki area of New Zealand (Benson, 1945), from Karroo Dolerites (Poldervaart, 1944), and around quartz xenocrysts in Iceland basalts (Hawkes and Guppy, 1925).

In many of the examples from basic minor intrusions and lavas, reference has been made to the formation of a glass between the augite corona and the xenolith (Benson, 1945), Knopf (1938), Thomas (1922), Reynolds (1940), Holmes (1936), and Poldervaart (1946). From this glass which must be regarded as a transfusion product of the quartzite xenolith by the addition essentially of magmatic potash, soda and alumina, tridymite, potash-soda feldspar and a few small grains of pyroxene have sometimes crystallized. In more slowly cooled rocks the glass appears to be represented by an inner feldspathic zone of similar bulk composition as at Ballachulish, Colonsay (Reynolds, 1936), and the Braefort Outer Sill, Fife (Campbell, Day, and Stenhouse, 1932). Holmes and Reynolds considered that this material, developed by replacement in the solid state, later became mobile. In some cases it has been suggested that it was developed before the corona was formed, but it is clear from a study of the Ballachulish occurrences and from the work of Benson and Thomas that in these cases at least the feldspathic zones were developed inside the early augite corona.

Descriptions of the action of acid rocks on quartzite xenoliths are not so frequent. Daly (1928) has described the alteration of quartzite inclusions in the Bushveld syenite and granite where the unaltered quartzite contained little else but quartz. In the metasomatized xenoliths much feldspar occurs and hornblende with diopside cores

is found in subordinate amount. Here there is no reference to a mafic corona, but chemical analyses show that considerable alumina, potash, and soda were introduced into the quartzite, whereas lime, iron, and magnesia were added in only small amount. In view of the considerable replacement which has occurred, it is possible that reaction has been more prolonged and that any early formed coronas have now disappeared.

From the Ilimausak region of South Greenland, Ussing (1912) has described inclusions of sandstone with mafic coronas (Plate XV, fig. 2), not more than a quarter of an inch in width. One such inclusion and its corona have been examined by the author and its similarity with the Ballachulish occurrences is very marked. In the xenolith itself the quartz grains are rounded, contain tiny needles of apatite, and many have been partly replaced by the interstitial perthitic microcline (Text-fig. 1*c*). Only rarely do the ferromagnesian minerals enter the xenolith itself. The corona, too, is very similar to those from Ballachulish and consists of stumpy anhedral grains of zoned pyroxene (aegirine-augite), some of which are mantled by a brown alkali amphibole. Poikilitic plates of perthitic microcline with albite cores and quartz grains, with nests of tiny apatites in the leucocratic constituents, recall textural features of the Ballachulish coronas. Again it appears that the formation of the mafic corona has preceded the slower process of replacement and mechanical disintegration of the xenolith by the feldspathic constituents.

Quartzite xenoliths enclosed in the hornblendite from Kiloran Bay Colonsay have been described by Reynolds (1936). Here very similar features are exhibited although in the formation of a corona around the quartzite cores, ferromagnesian minerals do not play so great a part and some have rims composed largely of pinkish alkali feldspars. Alteration of the xenoliths by the two feldspars appears to have proceeded on similar lines to the Ballachulish and Ilimausak occurrences with replacement of the quartz by hornblende playing a lesser part. Again, the incursion of the feldspars into the xenoliths has been effected to some extent by the wedging apart of neighbouring quartz grains along their junctions, although considerable direct replacement of the quartz has undoubtedly taken place. The minor role played by the ferromagnesian constituents in this case is not surprising if the hornblendite is considered to have been intruded as a mesh of hornblende crystals with an interstitial feldspathic partial magma which was the active agent in the reactions.

We see therefore that wherever quartzite xenoliths exhibit reaction with the enclosing rock three features of varying importance are evident. These are:—

(1) The crystallization of the mafic constituents of the magma as a corona to the xenoliths. Augite is frequently the earliest ferromagnesian mineral to be formed here.

(2) Alteration of the xenoliths themselves mainly by the feldspathic constituents of the magma working in along grain boundaries, and a replacement of the quartz especially by potash feldspar and to a lesser extent by sodic plagioclase and ferromagnesian minerals.

(3) The concentration of the volatile constituents of the magma around rather than inside many of the xenoliths.

The formation of the corona appears to have been relatively a rapid process compared with replacement in the xenolith and the appearance of augite prisms in the corona, often with a radial arrangement has very frequently been reported. In basaltic rocks its appearance might be attributed to crystallization of the phase with which the magma was saturated to provide heat for the solution of the quartz, but even in undersaturated rocks where a magnesian olivine was separating, augite appears in the corona where hypersthene might have been expected (Wells, 1951).

The only occurrences known to the author of hypersthene investing quartzite xenoliths are those described by Knopf (1938) and Rinnhe (1895) where the rhombic pyroxene has crystallized from the glass transfusion product. These glasses when analysed have proved to be lime poor. Benson (1945) has also recorded the presence of early hypersthene associated with titanaugite in veins traversing a few quartzite xenoliths but the rhombic pyroxene appears to have become unstable.

The tendency to form a lime-rich clinopyroxene rather than hypersthene in basic rocks when silica is added to the magma can probably be understood by analogy with an undersaturated liquid in the system diopside-forsterite-silica (Bowen, 1914), where the addition of sufficient silica would cause the liquid to leave the forsterite-clinopyroxene boundary curve and move across the clinopyroxene field towards the clinopyroxene-silica boundary with the separation of an ever more lime-rich pyroxene.

On this point it is of interest to record Poldervaart's (1946) observations on a vein of olivine tholeiite cutting coarse-grained Burghersdorp sandstone. The olivine has become unstable and has either disappeared or been altered to bowlingite where protected by pyroxene. Lime-poor pyroxene has failed and the augite shows abnormal zoning from cores (γ 1·704 and 2V 30–37°) to margins (γ 1·713, 2V 50–51°).

Whereas the ferromagnesian constituents of the magma and lime have contributed largely to the formation of the coronas, alkalies, and alumina appear to have become concentrated in the transfusion

products or in the recrystallized or replaced portions of the xenoliths. Moreover, when ferromagnesian constituents have been shown to enter the xenoliths, e.g. Wells (1951), Reynolds (1936), and Holmes (1936), iron appears to have entered preferentially to magnesia, whereas in the formation of the coronas the reverse is the case.

Earlier in this paper it was remarked that where they were most extensively developed the coronas around the Ballachulish quartzite xenoliths bore a resemblance to some rocks of the appinite suite. The characters of this group have been reviewed by Deer (1950) who has pointed out the wide variation in their mineralogical composition. Generally they are characterized by a richness in green or brown idiomorphic hornblende which is usually colour-zoned, they may carry a minor amount of pale green augite and biotite may or may not be present, being characteristically absent in the augite-bearing types. The plagioclase is always of oligoclase or andesine composition and orthoclase and quartz may also be present in varying amounts. Apatite, sphene, epidote, and calcite are commonly relatively abundant accessories. From this it can be seen that the hornblende-rich zone of the Ballachulish coronas has affinities with the more acid varieties of appinite and in Table I, column A is given the analysis of a quartz-orthoclase appinite from Glen Tilt for comparison. The silica content of the hornblende-rich zone of the rims is a little higher than this type, but as rocks of the appinite suite have been shown to be derived in a number of different ways some involving contamination, the possibility of their formation by the large-scale assimilation of silica in an intermediate or acid magma should not be entirely discounted. In the south-eastern part of the Ballachulish Complex considerable areas of appinitic diorite and appinite occur and in them a few quartzite inclusions with mafic coronas have been found, but they are not of sufficient abundance to warrant serious consideration as a possible mode of origin for this particular area of appinitic rocks.

The author wishes to express his gratitude to Professor C. E. Tilley, Dr. S. R. Nockolds, and Professor J. B. Thompson for their helpful advice and criticism, and to Professor W. A. Deer also for help and encouragement during the progress of the work. Dr. S. R. Nockolds and Mr. R. S. Allen very kindly carried out the spectrographic determinations. Much of this work was carried out in the Department of Mineralogy and Petrology during the tenure of a Research Maintenance Grant from the University of Cambridge, assistance now gratefully acknowledged.

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EXPLANATION OF PLATE XV

FIG. 1.—Mafic corona to quartzite to xenolith, Kentallen "Granite" quarries. Pale inner zone is composed mainly of augite, sodic oligoclase, and quartz. In the dark outer zone, green hornblende, oligoclase, quartz, and sphene are the principal constituents. Dark area at top of figure is a pelitic band.

FIG. 2.—Quartzite xenolith with mafic corona, from quartz syenite, Kangerdluarsuk, South-West Greenland. Mafic rim is composed largely of aegirine-augite, a brown alkali-amphibole and microcline.

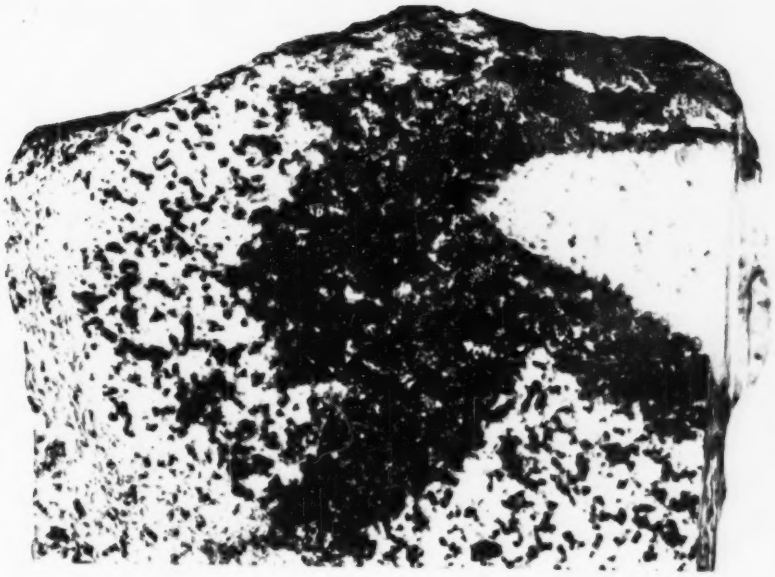

FIG. 1.

FIG. 2.

CORONAS TO QUARTZITE XENOLITHS.

Breconian: a Stage Name of the Old Red Sandstone

By the late W. N. CROFT

ABSTRACT

The Breconian stage of the Anglo-Welsh Old Red Sandstone is defined. The Breconian follows the Dittonian and precedes the Farlovian. In Breconshire, the Breconian comprises the Senni Beds and the overlying Brownstones. The Senni Beds have yielded a fauna and flora of Siegenian-Emsian age; the Brownstones are apparently unfossiliferous.

THE stage name Breconian was suggested in 1937 by Professor O. T. Jones, F.R.S., when supervising the writer's field-work in the Black Mountains. This appropriate and necessary term came into use at the XVIIIth International Geological Congress in London (White and Toombs, 1948; White, 1950, fig. 1; Westoll, 1951, 12, table III), and has since appeared elsewhere in the literature, but without explicit definition or particular reference to the type area. As proposed, the Breconian comprises that part of the Old Red Sandstone beds lying between the Dittonian and Farlovian stages of Mr. Wickham King, these beds being particularly well developed and exposed in Breconshire, where they form the magnificent escarpment of the Brecon Beacons. In the type area of the other stages of the Old Red Sandstone of the Anglo-Welsh province—the Ludlow district of Shropshire—the Breconian is poorly represented by the Clee Series, which has yielded no indigenous fossils (Ball and Dineley, 1952, 211).

In Breconshire, the type area, the Breconian comprises the Senni Beds and Brownstones *s.s.*, as shown in the following table. (The thicknesses given are approximate only.)

Farlovian	Grey Grits (20 feet, in Carmarthenshire).	
	Plateau Beds (130 feet).	*Holoptychius*, *Bothriolepis*, *Coccosteus*.
Breconian	Brownstones *s.s.* (1,250 feet).	No indigenous fossils found.
	Senni Beds (850 feet).	*Pteraspis dunensis*, *Drepanophycus*, *Gosslingia*.
Dittonian	Red Marls [upper part] (1,500 feet).	*Pteraspis crouchi*, *P. leathensis*.

Here, as elsewhere, the Senni Beds pass up gradually into the Brownstones without any break in sedimentation, and the mapped boundary between these formations is somewhat arbitrary. The junction of the Red Marls with the Senni Beds, though sharper, is also gradational.

The term Brownstones has a double usage. Brownstones (*sensu stricto*) exclude the underlying Senni Beds (Strahan, *et al.*, 1904, 3, 58), and the overlying Plateau Beds (cf. Dixon, 1933, 403). Brownstones (*sensu lato*) include both the Senni Beds, and their correlative strata, and the Plateau Beds. To remove the present ambiguity, it is recom-

mended that the use of the term in its wide sense should be discontinued, and that in any areas where Senni Beds cannot be recognized the name Brownstones (*s.l.*) should be replaced by a local stratigraphical term. The Plateau Beds are here excluded from the Brownstones on account of new observations on the field relations between these two formations, and because recent collecting in the Brecon Beacons has yielded well-preserved fish-remains from several localities in the Plateau Beds, indicating their Upper Old Red Sandstone age. I am indebted to Dr. E. I. White for the following identifications: *Holoptychius*, *Bothriolepis*, *Coccosteus*, *Sauripterus*, " *Dipterus*."

In addition to the Senni Beds and Brownstones *s.s.*, the Breconian includes the Clee Series of Shropshire, the Brownstones *s.l.* of Gower and the Forest of Dean, and the Cosheston Beds and Ridgeway Conglomerate of Pembrokeshire.

Wickham King (1925, 1934) in his classification has already made room for the Breconian stage. He recognized four major divisions, symbolized by the Roman numerals I–IV. These symbols are freely used on his 6 in. field-maps. For the division above the Downtonian he introduced the new name Dittonian. The third division, in which he placed the Brownstones [*s.l.*] of the Black Mountains and elsewhere, he referred to simply as Brownstones, giving no stage name. The uppermost division (IV), he named Farlovian to include the Farlow Sandstones of Shropshire, which have long been known to contain an Upper Old Red Sandstone fish fauna. In the papers cited Wickham King was mainly concerned with the two lower divisions. His letters and unpublished maps, however, make it clear that he includes in the Farlovian not only the Farlow Sandstones but also those other beds of Upper Old Red Sandstone age, which, in parts of the Anglo-Welsh province, are known to be unconformable on lower horizons. The first detailed description of the Farlovian of the type area will be given by Dr. H. W. Ball in a joint paper with Dr. D. L. Dineley on the Clee Hills area.

Wickham King himself has consistently included in the Dittonian only those beds—predominantly marls—which underlie the massive sandstones with marls of the Senni Beds and Brownstones and thus fall within the limits of his " mud belt ". The lithological boundary between his divisions II and III is essentially the same as that which has been mapped by the Survey Officers between their Red Marls and Red Sandstones sub-divisions. Moreover, he was influenced by a statement, since disproved (George, 1939), that the Brownstones [*s.l.*] of Gower are unconformable on lower beds; and he clearly states that the Brownstones [*s.l.*], together with the Ridgeway Conglomerate and Cosheston Beds, are post-Dittonian in age (King, 1934, 529, 542). The inclusion by a few writers of higher beds, up to and including the Plateau Beds, in the Dittonian was probably due

in part to the difficulty of determining the base of the Senni Beds in the Ferryside district of Carmarthenshire, and in part to the fact that Wickham King did not name his division III.

In the type area and to the east, near Abergavenny, the Senni Beds have yielded a considerable flora, including *Drepanophycus*, cf. *Psilophyton princeps*, *Dawsonites*, and *Gosslingia* (Croft & Lang, 1942). At one locality in Breconshire, high up in the Senni Beds, typical specimens of *Pteraspis dunensis* (Roemer) have been found (White, 1938). Both the fauna and the flora of the Senni Beds and their stratigraphical position show that they may be broadly correlated with beds classed as Siegenian-Emsian in the Continental succession. The only fossils found in the Brownstones *s.s.* occur in derived pebbles, probably of Silurian age. The age of the Brownstones is therefore conjectural. Elsewhere, as in Pembrokeshire, where the Breconian is much thicker and probably retains its youngest strata, the upper beds have yielded no fossils. Consequently, the upper limit of age of the Breconian is at present unknown.

Throughout the Black Mountains, and in neighbouring areas, the Senni Beds sandstones contain distinctive problematical structures, which are confined to these beds and serve as useful horizon markers.

The four stages into which the Old Red Sandstone of the Anglo-Welsh province is divided are, therefore, Downtonian-Dittonian-Breconian-Farlovian, in ascending order. The first three stages, which appear to form an unbroken stratigraphical sequence, are all of Lower Old Red Sandstone (Lower Devonian) age, although it is possible that the highest unfossiliferous beds of the Breconian may extend up into the Middle Old Red Sandstone. The Farlovian appears to be wholly of Upper Old Red Sandstone age.

I wish to thank several friends who have read and commented on this note. An account, by Dr. Gwyn Thomas and the writer, of the field relations between the Brownstones and the Plateau Beds is in preparation.

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Records of Irish Trilobites and Brachiopods

By Archie Lamont

Abstract

Records of certain trilobites and brachiopods illustrated in Charlesworth's *Geology of Ireland* are critically discussed.

Professor J. K. Charlesworth's *The Geology of Ireland: an Introduction* (Oliver and Boyd, 1953), with its many well-chosen sketch-maps, vertical sections, and photographs, is an essential book. To carp at detail may seem ungenerous, yet its Lower Palaeozoic stratigraphy scarcely represents any advance on that in G. H. Kinahan's *Manual of the Geology of Ireland* (1878). I am thinking especially of the drawings of fossils in the two books. Perhaps it may be permissible to make some comments on the trilobites and brachiopods illustrated in Charlesworth's book, and to record some observations on the occurrence of these forms, as named, in Ireland.

An illustration, admittedly not drawn by the author, in Charlesworth (page 34, fig. 1) depicts "*Trinucleus concentricus*". In America this name is a synonym of *Cryptolithus tesselatus* Green from the Trenton. Now, in Ireland, "*T. concentricus*" has been recorded erroneously from at least five different horizons. Some of these have been dealt with (Lamont, 1941*b*). The form that was so described from the Tramore limestone is *Eirelithus thersites* (Salter), and that from the Killey Bridge Beds of County Tyrone may be *C. elongatus* (Portlock), or *C. portlockii* (Salter), or a variety of either of these as distinguished by Reed (1952).

At last some new information can be given on "*Trinucleus concentricus* Eaton" (Baily, 1869, p. 16) from the pale grey shale of Slieveroe, County Wicklow. Material in the Royal Scottish Museum (1870. 12. 1323, 1325, 1326), examined by R. P. Tripp and the writer, appears to be a variety of *Tretaspis ceryx* Lamont. On the perforate fringe the I_3 row of pits only occurs at the side of the cheek and is slightly defective behind. On the posterior margin there are about four, not six, pits between genal spine and cheek. The genal spine is longer than the cephalon and is convex outwards. It carries a dorsal longitudinal groove corresponding with the girder inside the external (E_{1-2}) rows of pits. Tripp claims that *Eirelithus thersites* is also in the fauna. Another certainly there is *Flexicalymene* aff. *brevicapitata* (Portlock) probably of the Tramore limestone type with a glabella narrower than in the Tyrone form (Shirley, 1931, pl. ii, fig. 9) and somewhat overhanging the pre-glabellar field. *Lonchodomas* aff. *hastatus* Ruedemann with bent rostral spine is also present. The brachiopods are mainly undescribed species, some reminiscent of

Reed's Hovin faunas (1932). I have noted *Orthis* aff. *callactis* Dalman, *Cyrtonotella* (?) cf. *subfissicosta* (Reed), *C.* aff. *semicircularis* (Eichwald), *Hebertella* aff. *bellatrix* Reed, *Strophomena* aff. *asmusi* Verneuil early var. (Holtedahl, 1916, p. 50), *S.* cf. *deficiens* Reed, *Leptelloidea* (?) sp., *Chonetes* (*Eodevonaria*) *tenuissime-striata* (McCoy), *Skenidioides* aff. *craigensis* (Reed).

From Chair of Kildare the record of "*Trinucleus* (?) *concentricus*" (Reed, 1896, p. 592), Nils Spjeldnaes informs me, was probably based on small or young specimens of *Tretaspis kjaeri* Størmer having the fringe more steeply bent down in front of the glabella than in *T. kjaeri* mut. *radialis* Lamont from Portrane. The allied *T.* aff. *kjaeri* from the Upper Whitehouse beds of Scotland has two strong concentric girders on the underside of the fringe, which may necessitate founding a new genus for it. H. C. Stetson's reference (1927, p. 89) to *T. seticornis* from Chair of Kildare seems to be unsupported, like his reference to the same species from Wexford. Possibly he also errs (p. 88) in citing *Trinucleus fimbriatus* (Murchison) from Wexford, Tyrone, and Wicklow, and *Cryptolithus caractaci* (Murchison) from Wexford, Tyrone, and Waterford. Though I have not studied much County Wexford material, in the grey-green shales under the volcanics, at a locality 170 yards north of Duffcarrick Rocks, near Courtown Harbour, there is a large flattish variety of *Glyptorthis* cf. *crispa* (McCoy) like one characterizing the lower part of the Tramore Limestone: and larger than that in the Stinchar Limestone, at Aldons, Girvan, etc. (Lamont, 1941*a*).

A tantalising reference to "*Trinucleus concentricus*" at Knockshigowna Hill, County Tipperary, under the Old Red unconformity (Wynne and Jukes, 1862, p. 28; Harper, 1948, p. 54) also has not been reinvestigated. The Silurian succession thereabouts seems to range up from Gala-Tarannon (*Summ. Progr. Geol. Surv.* for 1897, p. 71), but Glenkiln and Lower Hartfell inliers occur.

Charlesworth's fig. 2 is of the Ashgillian "*Staurocephalus*" *globiceps* (Portlock), and resembles the Ayrshire one (Salter, 1865, p. 86, fig. 18) more closely than the Tyrone form (Salter, 1865, pl. vii, fig. 21*b*). Begg (1940, p. 298) provides excellent reasons for putting the species in the genus *Sphaerocoryphe* Angelin.

Charlesworth's fig. 3 of "*Ampyx nudus*" (Murchison) is not *Ampyx*, since only five thoracic segments are present, suggesting *Raphiophorus*. There is no proof that *A. nudus* is an Irish fossil, or *A. bisectus* Elles, or *A. salteri* Hicks, or "*A.*" *latus* McCoy. Whittard has identified *Ampyx mammillatus* Sars var. *austini* (Portlock) from the dark slightly baked Raheen beds above the Tramore Limestone with a form from the *Didymograptus bifidus* Zone in Shropshire (1940*a*, pp. 157–161), but the proportions of certain glabellar features differ (Lamont, 1941*b*, pp. 462–3).

On Charlesworth's fig. 4 of *Remopleurides laterispinifer* Portlock, the spinose extensions of the seventh thoracic pleurae are not sufficiently emphasized. Salter suggests this is the mature female of *R. colbii* Portlock, though Reed (1952, p. 109) preserves it as an independent species.

Fig. 5 in Charlesworth is entitled "*Aeglina binodosa*", but the rounded pygidium and general appearance are those of *Cyclopyge prisca* (Barrande) from Bohemia. In Shropshire *C. binodosa* is known from the Hope Shales and Stapeley Volcanic group (Whittard, 1940*b*). So far as I know, the species has not been found in Ireland.

Charlesworth's fig. 6 may be of *Illaenus centrotus* Dalman, but the species does not seem to be Irish. It has nothing to do with the "*Dysplanus centrotus*" figured with a query by McCoy (1851, pl. IE, figs. 19, 19*a*) from the Berwyn Hills as synonymous with *Illaenus bowmanni* (Salter). It is possible that *I. bowmanni* occurs in County Tyrone, and it may have been included among specimens grouped as "*I. centrotus*" by Portlock, but surviving specimens from Tirnaskea formerly so labelled are now referred by Reed to *I. tyronensis* Reed and to *I. linnarssonii* (Holm)? One imperfect example from the Bardahessiagh Beds, formerly termed "*I. centrotus*", is now put as *Illaenus* sp. (Reed, 1952, pp. 114–15).

Professor Charlesworth also figures as Irish "*Dalmanites* (*Phacops*) *caudatus*" (sic) and "*Calymene blumenbachii*". I have not yet been able to check the reputed occurrence of *D. caudatus* (Brünnich) in the Ferriter's Cove beds, County Kerry, which appeal to me as older than the Wenlock shales and limestone if one considers these, in the strict sense, as Upper Wenlock. I have also not yet seen typical *C. blumenbachii* Brongniart from Ireland, and certainly not the rare and distinctive *C. allportiana* Salter (1865, text-fig. 20; Shirley, 1933, pl. i, fig. 12), which is the form figured by Charlesworth. Examination of the Ferriter's Cove and Croaghmarhin beds for *Calymene* spp. has, however, not been completed.

The records of "*Calymene blumenbachii*" and "*C. senaria*" from the conglomeratic greywacke with andesite ash (Reynolds and Gardiner, 1896, p. 589) under the Chair of Kildare Limestone are at present being revised. One small Sedgwick Museum specimen (SM. A 13811*b*) resembles *Flexicalymene onniensis* Bancroft (1949, pl. ii, fig. 37). Another little specimen (SM. A 13806) has the glabellar outline of *F. meeki* (Foerste) of the broad type, but differs in marked overhang of the anterior part of the pseudofrontal lobe over the preglabellar field. It also differs from an earlier variety in the Kila silty muds at Craighead, Girvan, which has a longer preglabellar field and less strongly developed anterior border. The identifications of associated brachiopods in Reynolds and Gardiner's paper are only approximate.

The *Dinorthis flabellulum* is apparently a late variety of J. de C. Sowerby's species with bifurcation and trifurcation of ribs, and the record of "*Strophomena expansa*" J. de C. Sowerby should be *Rafinesquina concentrica* (Portlock) var.

Of brachiopods in Charlesworth's *Geology of Ireland* (p. 37), one may say the appearance of *Longvillia grandis* (J. de C. Sowerby) in Ireland is "doubtful" (Reed, 1952, p. 45) and probably this identification is a mistake for *Rafinesquina concentrica* of the Bardahessiagh Beds, Tyrone, while the occurrence in Ireland of *Parmorthis elegantula* (Dalman), *sensu stricto* has still to be proved. I have been looking in vain for it in the Croaghmarhin Beds, County Kerry.

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PUBLICATIONS RECEIVED

New Zealand Geological Survey : Bulletin 50 n.s. The Geology of Geraldine Subdivision, S102 Sheet District. By H. W. Wellman. 72 pp. with 14 text-figs and coloured map in folder. Wellington, 1953. Price 15*s.* (paper covers).

New Zealand Geological Survey : Palaeont. Bull. No. 17. Additional Lower Pliocene Mollusca from Otahuhu, Auckland. By C. R. Laws. 35 pp. with 5 half-tone plates. Wellington, 1950. Price 5*s.*

New Zealand Geological Survey : Palaeont. Bull. No. 21. Divisions and Faunas of the Hokonui System (Triassic and Jurassic). By J. Marwick. 141 pp. with 17 half-tone plates. Wellington, 1953. Price 20*s.* (paper covers)

New Zealand Geological Survey : Palaeont. Bull. No. 22. Upper Mesozoic and Cainozoic Spores and Pollen Grains from New Zealand. By R. A. Couper. 77 pp. with 9 half-tone plates. Wellington, 1953. Price 8*s.* 6*d.* (paper covers).

Nyasaland Protectorate : Annual Report of the Geological Survey Department for the year 1952. 32 pp. with 8 plates (black and white maps). Zomba, Nyasaland, 1952. Price 4*s.*

Geological Survey of Canada : Bull. 26. Bedrock Geology of the Seaboard of Labrador between Domino Run and Hopedale, Newfoundland. By E. H. Krank. 39 pp. with 5 half-tone plates and coloured map in folder. Ottawa, 1953. Price 50 cents.

Geological Survey of Canada : Mem. 270. Weldon Bay map-area, Manotiba. By J. Kalliokoski. 80 pp. with 4 half-tone plates and coloured map in folder. Ottawa, 1952. Price 75 cents.

Geological Survey of Canada : Mem. 271. Batty Lake map-area, Manitoba. By D. S. Robertson. 55 pp. with 3 half-tone plates and 2 coloured maps in folder. Ottawa, 1953. Price 75 cents.

Polskie Towarzystwo Geologiczne : Regionalna Geologia Polski ; tom 1, Karpaty ; zeszyt 2, Tektonika (edited by M. Książkiewicz). pp. 207-453, with 100 text-figs. and plates xvii-xl in folder (in Polish). Krakow 1953. zł. 60.

Mineria : Organo del Instituto de Ingenieros de Minas del Peru. Ano 1, No. 3, May, 1953. 60 pp. No price.

T. EASTWOOD. *British Regional Geology :* Northern England (third edition). pp. vi + 71, with 26 figs. and 8 plates. H.M. Stationery Office, London, 1953. Price 4*s.*

Geological Survey, Sudan. Colour-printed geological maps: Anglo-Egyptian Sudan, 1 : 1,000,000, sheet 55, *Khartoum* (1952), and *Eastern Khartoum Province*, 1 : 250,000 (1953). Price 500 *m/ms.* each.

Norsk Polarinstitutt, Oslo. Meddelser nr. 72, *Drivisen ved Svalbard* 1924–39 av K. Omdal, *Kr.* 2.50; nr. 73, *Noen iakttagelser over isbreenes tilbakegang i Hornsund, V. Spitsbergen*, av A. Heintz, *Kr.* 3.50; nr. 74, *Preliminary note on the Geology of Western Dronning Maud Land*, by E. F. Roots *Kr.* 2.00; nr. 75, *The Currents of the Coast of Queen Maud Land*, by H. U. Sverdrup, *Kr.* 1.00; nr. 76, *Flateinnholdet av Breer og Snøfonner i Norge*, av A. Hoel, *Kr.* 1.50.

REVIEWS

PRINCIPLES OF GEOCHEMISTRY. By BRIAN MASON. pp. vii + 276, 42 figs. John Wiley and Sons, New York (Chapman and Hall, Ltd., London), 1952. Price 40*s*.

This excellent little book is based on a course of lectures given by Professor Mason at Canterbury University College and later at Indiana University.

An introductory chapter on the scope and history of geochemistry is followed by others on the earth in relation to the universe, the structure and composition of the earth, some thermodynamics and crystal chemistry, magmatism and igneous rocks, sedimentation and sedimentary rocks, the hydrosphere, the atmosphere, the biosphere, metamorphism and metamorphic rocks, and the geochemical cycle.

In each of the chapters Professor Mason has managed to condense a great deal of information and yet remain lucid. Moreover, each is followed by a list of selected references enabling the student to study further the subjects mentioned in the text.

This book should be read by all geologists, though the price may deter many from buying it for themselves.

S. R. N.

THE EARTH, ITS ORIGIN, HISTORY, AND PHYSICAL CONSTITUTION. By HAROLD JEFFREYS. Third edition, pp. xi + 392, with 30 figs. and 10 plates. Cambridge University Press, 1952. 70*s*.

"The Earth" is one of the established classics in geology, and it would seem impertinent to do more than welcome a new edition but for the fact that it is greatly changed. In view of present uncertainties the four chapters on the origin of the Solar System have been dropped, although the sub-title is unaltered. The rest has been rewritten, expanded, and reorientated, and results in a work with more direct bearing on geological thought. Although it is still primarily a geophysical study several branches of the subject are omitted, such as terrestrial magnetism, probably also for the reason that little can yet be written with finality. The mathematical treatment, although forbidding to many, punctuated a text always easy to read. In this edition fewer obstacles are put in the way of the non-mathematical reader, and the subject-matter is developed with still greater clarity. There is a new bibliography and very full it is, except that the titles of papers are not given.

Chapter I describes the mechanical properties of rocks, in particular their elastic and non-elastic behaviour. There is insufficient understanding of the yielding processes in rocks for quantitative application to structural geology. Here as elsewhere the importance of metamorphic rocks may be underestimated. The theory of elastic waves is expounded in chapter II and applied in chapter III to the structure of the earth from earthquake data. This is a non-mathematical treatment better ordered than in the second edition, and giving a clear account of the snares which beset seismological interpretation. Some may not agree with the identification of certain layers with surface rock types, for example the "granitic" layer, but there is always a frank separation of fact and opinion which disarms criticism. Much new information since the 1928 edition is included, especially on regional crustal seismic velocities and on the inner core.

There is then a succession of chapters with a geodetic flavour on the figure of the earth, isostasy, and tides. Chapter IX on the age of the earth reviews many methods including Holmes's lead isotope estimation and the subse-

quent modifications of this method. This is followed by a chapter dealing with the thermal history of the earth and the distribution of radioactivity in it.

Chapter XI, "The Origin of the Earth's Surface Features," is probably of most interest to geologists. The thermal contraction theory of the origin of mountain ranges is upheld both by removing some current misconceptions as to its nature and by discovering a previously neglected term in the initial temperature distribution of the earth which requires a further shortening along a great circle of 400 km. Inexperience in handling geological material results in a clumsy treatment of some topics but the structure of the argument survives giving the impression that a master builder is at work.

Throughout the book there are innumerable fertile asides and the final paragraphs are highly suggestive. A subcrustal zone of tension may develop beneath the level of no strain in a contracting crust and the repercussions of this on the origins of rift valleys and island arcs brings one to the end without wishing to stop reading.

The high standards of the Press are maintained making the book a pleasure to handle, but with such a momentous text the few half-tone geological views are almost pathetic, especially Plate VII with two views faintly reproduced and wrong way round.

W. B. H.

INTERNATIONAL GEOLOGICAL CONGRESS. Publications of the Nineteenth International Geological Congress, Algiers, 1952.

A full Report of the Proceedings of the XIX International Geological Congress is now in the press, and is to be issued towards the end of this year; what has already been distributed constitutes an impressive publication on a lavish scale.

The main portion takes the form of three series of Regional Monographs, too numerous to mention individually: 1re Série, *Algérie*, 28 fascicules (4000 francs), 2e Série, *Tunisie*, 7 fascicules (1500 fr) and 3e Série, *Maroc*, 7 fascicules (6000 fr). These are obtainable separately at the prices quoted, and even individual fascicules can be bought separately.

In addition to these valuable local guides, the Congress authorities have published an atlas of photographs of Algeria, reproduced in excellent half-tone plates (4to) with a key map to all localities, and tracing-overlays to many of the plates (1000 fr); an international list of geologists, taking the place of the pre-war "Geologen und Mineralogen Kalender", containing over 25,000 names (500 fr); symposia on the Gondwana Series (1 volume, 4to, 550 fr), and on Iron Ores of the World (3 vols., 4to, 3000 fr); a geological map of North Africa to the scale of 1 : 2,000,000, in two sheets (3000 fr) and of Algeria, 1 : 500,000, in six sheets (3500 fr); and abstracts of communications read at the Congress.

The complete set, priced at 23,450 francs, is obtainable from the Secrétariat du XIXe Congrès Géologique International, Faculté des Sciences, Alger.

O. M. B. B.

SUMMARY OF PROGRESS OF THE GEOLOGICAL SURVEY OF GREAT BRITAIN AND THE MUSEUM OF PRACTICAL GEOLOGY FOR THE YEAR 1951 (with Report on the Geological Survey Board and Report of the Director). iii + 76 pp. Department of Scientific and Industrial Research (H.M. Stationery Office), 1953. Price 2*s*. 6*d*.

At the end of last year, we were able to record the resumption of the *Bulletin of the Geological Survey*, and we welcome now the reappearance of

the well-known *Summary of Progress* which was discontinued after 1938 in favour of "utility" wartime Annual Reports of the Geological Survey Board. The present publication follows the familiar lines of pre-war Director's, District, and Sectional Reports. It includes as an appendix a List of Geologists in post in 1952, and these 79 names reveal a gratifying post-war expansion of the Survey, although it has fallen a little short of original intentions. There is no index, but we hope that in future years it will be possible to include this essential feature.

O. M. B. B.

DEEP-SEA RESEARCH. Edited by L. FAGE, C. D. OVEY, and MARY SEARS. Vol. 1, No. 1, 64 pp. (10 in. by 6¾ in.). Pergamon Press, London, 1953. Published quarterly, price £4 10*s.* per volume.

This is the first number of a new international journal to be devoted to investigation of the deep-sea floor and its scope is well indicated by the following list of contents :—*J. D. H. Wiseman*, International collaboration in deep-sea research ; *J. D. H. Wiseman* and *C. D. Ovey*, Definitions of features on the deep-sea floor ; *H. Pettersson*, The Swedish Deep-sea Expedition ; *B. C. Heezen*, *M. Ewing*, and *E. T. Miller*, Trans-atlantic profile of total magnetic intensity and topography, Dakar to Barbados ; *F. Bernard*, Rôle des Flagellés calcaires dans la fertilité et la sédimentation en mer profonde ; *J. D. H. Wiseman* and *H. I. Hendey*, The significance and diatom content of a deep-sea floor sample from the neighbourhood of the greatest oceanic depth ; and *G. S. Ritchie*, Further notes on the greatest oceanic sounding and the topography of the Marianas Trench. The journal has been established on the initiative of the Joint Commission on Oceanography of the International Council of Scientific Unions and we wish it every success.

O. M. B. B.

DAS HOLZMADENBUCH. By BERNARD HAUFF. (Schriften der Deutschen Naturvereins, N.F., 1953.) Hohenlohe'sche Buchhandlung Ferdinand Rau, Öhringen. *DM.* 8.75.

The bituminous *Posidonia* shales and limestones of the Upper Lias have made Holzmaden in Württemberg palaeontologically one of the most celebrated localities in the world. This fame is due mainly to one man, Bernard Hauff senior, father of the present author, who first perfected methods for developing the fossil reptile skeletons found in the quarries. This excellent little book gives an account of those methods and of the quarries, historical, palaeontological, and stratigraphical. It also tells the story of the life of Bernard Hauff senior, who was brought up to work in his father's quarry, and at 17 was sent to Tübingen University at the instigation of Oskar Fraas to learn palaeontological techniques, but had to return after only six months owing to the family's financial stringency. Thereafter, in the early mornings before the manual labour of the day began, and late into the night, he toiled at developing his specimens. His work is now represented in museums all over the world and is the object of universal admiration and instruction. He and his pupils have developed more than 300 complete skeletons of *Ichthyosaurus* alone, and in addition many *Mystriosaurus*, *Pelagosaurus*, *Plesiosaurus*, and pterodactyls.

The main part of the book consists of an annotated list of the fauna and flora of the Holzmaden *Posidonia* shales, illustrated with 80 full pages of

superb half-tone photographs. Thirty plates are devoted to the reptiles and include views showing venation of the skin, embryos in place between the ribs, and other interesting features. Of the remaining plates, 25 illustrate fish, the others crustaceans, crinoids, mollusca, plants, and borings. Next to the saurians the high-light is the crinoids, which are of marvellous perfection and beauty. They are attached to pieces of driftwood, on which they compete for place with masses of *Inoceramus dubius*. One group of crinoids attached to a log 13 metres long covers an area 18 m. by 6 m.

There is a concluding chapter on the origin of the *Posidonia* shales, a palaeogeographical map, glossary of technical terms, and a note on the etymology of the names of the fossils. The book is a pious filial memorial to Bernard Hauff. It is to be most warmly recommended.

W. J. A.

THE SEA COAST. By J. A. STEERS. pp. xii and 276, with 52 figs. and 32 pls. (8 in colour). The New Naturalist Series. Collins, London, 1953. 25*s*. net.

Seven years ago Professor Steers gave us the first comprehensive account of "The Coastline of England and Wales". The present volume deals with Scotland as well, but being about half the size of this earlier book, it clearly cannot be as complete or as detailed. He has adjusted his methods to this limitation of space by using a systematic treatment and analysing types of coastline, cliffed coasts (erosional) and lowland (depositional), illustrating the principles underlying their evolution and form by a number of detailed studies of varieties within each type. The book is beautifully illustrated with plates in colour and in black-and-white, and is generously supplied with maps and sections.

A. A. M.

MORPHOLOGICAL ANALYSIS OF LAND FORMS. A Contribution to Physical Geology. By Professor Dr. WALTHER PENCK. Translated by HELLA CZECH and KATHERINE CUMMING BOSWELL. xiv and 429 pp., with 12 plates and 20 text-figures. Macmillan and Co., 1953. 42*s*. net.

The persuasive writing of Professor W. M. Davis, backed by the high prestige of the American School of Geomorphology, gave to his pronouncements and particularly to his concept of the Cycle of Erosion, something of the indisputability of a gospel. Davis and his disciplies tacitly assumed that uplift and denudation were successive processes and that, if the course of the cycle was interrupted by uplift, the cycle recommenced when the uplift (rejuvenation) was completed, and not until then. Penck argued that this was a rare and special case, that endogenetic and exogenetic displacements (of the crust and of waste material respectively) occurred together, the ratio of their intensities governing the modelling of the crust. Since the erosional processes can be observed and the form of the crust can be measured, the third factor in the equation can be deduced, and for him morphological analysis was primarily a means of deducing the course of crustal movement from the exogenetic processes and the morphological features. Clearly the first step must be a careful examination of each of the operating factors involved. Davis had assumed too readily that these are well understood, but Penck took nothing for granted and worked systematically through them all; the composition and deformation of the crust, the nature of weathering, the mobility of weathering products, the nature of mass move-

ments (gravity operated), the nature of erosion (transport in channels), the form of deposited waste and the control by base-level. In his theoretical treatment of land forms he uses the method of the differential calculus, considering for each small fragment of the crust its net movement, the resultant of crustal displacement on the one hand and denudation and deposition on the other. In this way several sequences of developing forms, waxing, waning, etc., are arrived at. This discussion of principle leads to an analysis of various forms of slope, breaks of slope, linking of slopes, and associations of forms, each explained by diagrams and illustrated by photographs.

At every stage he is very careful to define his terms, and his terms constitute a whole new vocabulary. The coining of English equivalents for such words as " aufbereitung " or " haldenhang " or the equating of them with existing geomorphological terms has been the most difficult part of the translation. There is a glossary of about 150 terms.

The son of a famous geographer (Albrecht Penck), Walther had made great contributions to geology and geomorphology before he died at the early age of 35 with his great work unfinished. It was published posthumously by his father. By a tragic coincidence one of his translators (Miss Boswell) also died (at Beni Abbès while attending the Nineteenth International Congress of Geology) before this present work saw publication. English-speaking geologists and geomorphologists owe to her and her collaborator, Dr. Hella Czech, a great debt, not only for making the important and violently controversial views of Walther Penck available, but also for providing a biography, a bibliography, and about 50 pages of explanatory notes by which one may know the man as well as his work.

The translators have wisely adhered closely to the original German text although it is wordy and often obscure, but Miss Boswell has provided a short cut to the conclusions by means of a chapter-by-chapter summary of about 60 pages.

A. A. M.

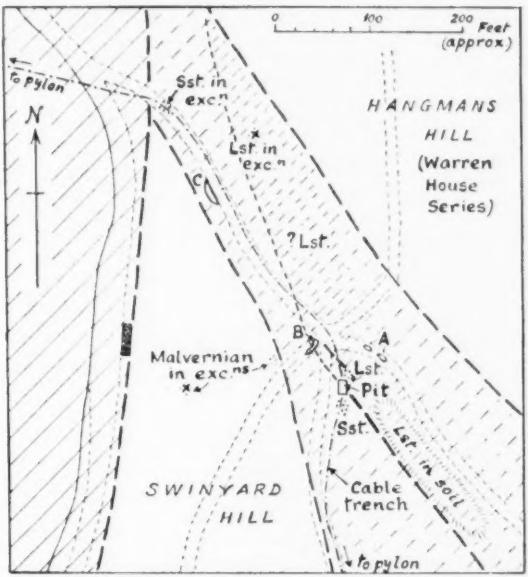
CORRESPONDENCE

A TEMPORARY SECTION IN THE MALVERNS

SIR,—During the excavation which preceded the laying of an electric cable across the southern end of Hereford Beacon, the rocks exposed in a short section of the cable trench were observed by one of us (R. E. B.) during a chance visit. The locality, shown on the accompanying sketch-map, is at the northern end of Groom's " Silurian Pass ", between Swinyard Hill and Hangmans Hill. Near the junction of the paths a pit was excavated and had been lined before the time of the visit; but the spoil from it consisted of purple Mayhill Sandstone (Upper Llandovery) at the south end of the pit, and an argillaceous limestone at the north end. In an accessible part of the trench, which followed the track on the east side of Swinyard Hill, limestone was seen faulted against shale just north of the pit. The fault trended north-west and dipped steeply, but the trench was too shallow to allow of proper estimation of the dip. The limestone formed the south-west wall of the fault, and was broken by slickensided surfaces, one group of which were striking approximately north-east and dipped steeply south-east. The slickensides indicated a mainly vertical movement. Scanty fossils (corals and

brachiopods) from the limestone would agree with a Wenlock age, but would not exclude Woolhope.

Known exposures of limestone lie in the old track (point A on sketch-map) east of the trench, and are now partly covered with spoil. About 90 yards to the north, spoil from an excavation for a pylon contained much limestone. Limestone is also exposed at B on the map. The evidence therefore suggests that a belt of limestone is present in the Silurian outcrop here, and a suggested boundary for it is shown by a dotted line. The exposure marked C on the map is mass of Pre-Cambrian, possibly forming a fault-slice within the Silurian.



Sketch-map of the Silurian area (northern end) between Swinyard Hill and Hangmans Hill, to show localities referred to in text. Diagonal shading, Silurian; Pre-Cambrian unshaded. Heavy broken lines are faults. (Lst. = limestone; Sst. = sandstone; excn. = excavation.)

At the time of the visit (October, 1952) most of the trench had been filled in, and we should be interested to hear of observations made by anyone who happened to see the locality before that date, when access to the excavation was better.

The new evidence may necessitate some adjustments of earlier mapped lines in what is clearly a complex fracture zone. The boundaries shown on the sketch are a tentative interpretation of the observations available.

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1st October, 1953.

THE PROSICULA OF *RETIOLITES GEINITZIANUS* BARR

SIR,—A boulder of grey calcareous mudstone found in an urban district of Berlin contained *Monograptus priodon* and *Retiolites geinitzianus*, suggesting Upper Valentian or Lower Wenlock age. After acid treatment with HCl and HF, adult rhabdosomes of *Retiolites geinitzianus* were obtained, together with numerous specimens in various stages of development.

The main discovery recorded here is an early ancora stage of which I obtained three specimens. Two of these show the distal half of a prosicula, opening towards the bifurcating ancora structure. The third specimen, which unfortunately disintegrated, represented a later stage of development of the ancora and retained a tiny fragment of the prosicula. Still later stages, with $th1^1$ and $th1^2$ do not show any trace of the prosicula.

Prosicula and ancora of *Retiolites geinitzianus* Barrande. B.M.N.H., H 4541. × 25 approx.

The distal half of the prosicula of the figured specimen shows four strengthening rods, one of which is continued beyond the opening of the prosicula as the axis of the ancora; a helical line has not been observed on the prosicula. No transverse growth-lines are visible anywhere on the specimen, and it is obvious that a chitinized metasicula *sensu stricto* did not exist in *Retiolites geinitzianus* even at this stage, but it is possible that the axis of the ancora may correspond to the virgella.

In the figured specimen the ancora shows primary and secondary bifurcations: the whole specimen as preserved is slightly less than 1 mm. long.

The growth of the chitinous skeleton of *Retiolites geinitzianus* is thus directly comparable with that of biserial graptolites. From the formation of the prosicula to the earliest stage of bifurcation of the ancora, growth is downward. In the later stages the periderm grows upward, surrounding the axis of the ancora and the prosicula. Beyond the prosicula, the axis of the ancora grows upward as a virgula, sending branches to the lateral walls at regular intervals, and extending beyond the growing distal end of the rhabdosome.

There are now three successive stages of retioloid development which illustrate progressive reduction of the pro- and metasicula. In the Upper Ordovician (Ostseekalk) *Retiolites regimontanus* both pro- and metasicula are fully chitinized. In *Retiolites geinitzianus* only the prosicula is chitinized, the axis of the ancora probably representing the metasicula. In the Lower Ludlow *Retiolites tenuis*, *mancki*, *simplex*, *tetracanthus* even the prosicula is no longer chitinized, the ancora passing directly into the virgula.

The recognition of a prosicula attached to the axis of the ancora confirms the interpretation of the retiolitid rhabdosome given by Eisenack (1951), though in his plates and drawings he reverses the normal orientation of a graptolite rhabdosome.

W. G. KÜHNE.

BERLIN—WILMERSDORF
NASSAUISCHE STR. 62.
July, 1953.

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